Minimum Levels and Proposed Guidance Levels for Lake Hancock in Polk County, Florida

May 24, 2017

Resource Evaluation Section
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Cover: Lake Hancock in January 2005 (Southwest Florida Water Management District files).

Executive Summary

This report describes the development of minimum and proposed guidance levels by the Southwest Florida Water Management District for Lake Hancock in Polk County, Florida. Following Board approval on October 27, 2015, minimum levels were adopted into District rules on November 10, 2015 and became effective on November 30, 2015. The minimum levels replaced previously adopted guidance levels included in District rules. The proposed guidance levels described in this document were not adopted into rule because they were based on water level conditions that existed prior to the recent modification of the District P-11 water control structure at the lake outlet. Current and future water levels conditions in the lake are expected to differ from previous conditions based on operation of the P-11 structure for storage of water in the lake and release of the stored water to support recovery of minimum flows in the Peace River.

Minimum levels are the levels at which further water withdrawals would be significantly harmful to the water resources or ecology of the area (Section 373.042(1)(b), Florida Statutes; F.S.). Minimum levels adopted by the District for lakes, wetlands and aquifers, and minimum flows adopted for rivers, springs and estuaries are used to support water resource planning and permitting activities. Guidance levels are adopted for lakes and used as advisory guidelines for construction of lakeshore development, water dependent structures, and operation of water management structures.

The Minimum Lake Level and High Minimum Lake Level for Lake Hancock, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 are listed in Table ES-1 (corresponding elevations in feet above the North American Vertical Datum of 1988 are also included for comparative purposes) along with descriptions for the levels included in District rules (Rule 40D-8.624, F.A.C). These minimum levels were developed using current District methods for establishing minimum levels for Category 2 Lakes, which are lakes that are contiguous with at least 0.5 acres of cypress-dominated wetlands where structural alterations have substantially affected water levels. The levels were also developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.).

The adopted minimum levels for Lake Hancock are considered to currently be met. Given that the P-11 structure at the lake outlet, which can be used to control lake water levels, was recently been modified to increase storage in the lake basin for release to the Peace River to recover minimum flows, the High Minimum Lake Level and Minimum Lake Level for Lake Hancock are also expected to be met for the next 20-year planning period.

The District plans to continue regular monitoring of water levels in Lake Hancock and will also routinely evaluate the status of the lake's water levels with respect to the minimum levels established for the lake. If the need for recovery of minimum levels in the lake is identified, the Southern Water Use Caution Area recovery strategy (Rule 40D-80.074, F.A.C. and SWFWMD 2006) would be applicable.

Table ES-1. Minimum and proposed guidance levels for Lake Hancock and level descriptions.

Minimum and Guidance Levels	Elevation (feet above NGVD29[a])	Elevation (feet above NAVD88[b])	Level Descriptions
High Guidance Level	98.8 [c]	97.9 [c]	Advisory guideline for construction of lake shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ten percent of the time on a long-term basis.
High Minimum Lake Level	98.8	97.9	Elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis.
Minimum Lake Level	97.6	96.7	Elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis.
Low Guidance Level	96.7 [c]	95.8 [c]	Advisory guideline for water dependent structures, information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis.

[a] National Geodetic Vertical Datum of 1929.
[b] North American Vertical Datum of 1988.
[c] Proposed guidance levels were not adopted into District rules.

Acknowledgements

The authors would like to thank several of our Southwest Florida Water Management District colleagues for their contributions to the work summarized in this report. We thank Richard Gant for his assistance with field-data collection and review of previous draft project report, Harry Downing for providing information associated with future operation of the District water control structure at the Lake Hancock outlet, and Jason Patterson for providing relevant water-use information. We also thank our former District colleague, Lisa Henningsen, for her assistance with field-data collection and review of previous draft reports for the project.

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Introduction

Establishment of Minimum and Proposed Guidance Levels for Lake Hancock

This report describes the development of minimum and proposed guidance levels by the Southwest Florida Water Management District (District or SWFWMD) for Lake Hancock in Polk County, Florida. The levels were developed using peer-reviewed District methods for establishing guidance levels and minimum levels for lakes. The levels were also developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.).

Following Board approval on October 27, 2015, minimum levels for Lake Hancock were adopted into District rules on November 10, 2015 and became effective on November 30, 2015. The minimum levels replaced previously adopted guidance levels that were included in District rules. The proposed guidance levels described in this document were not adopted into rule because they were based on water level conditions associated with conditions that existed prior to the recent modification of the District P-11 water control structure at the lake outlet. Current and future water levels conditions are expected to differ from previous conditions based on operation of the P-11 structure for storage of water in the lake and release of the stored water to support recovery of minimum flows in the Peace River.

Minimum Flows and Levels Program Overview

Legal Directives

Section 373.042, Florida Statutes (F.S.), directs the Department of Environmental Protection or the water management districts to establish minimum flows and levels (MFLs) for lakes, wetlands, rivers and aquifers. Section 373.042(1)(a), F.S., states that "[t]he minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Section 373.042(1)(b), F.S., defines the minimum water level of an aquifer or surface water body as "…the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area." Minimum flows and levels are established and used by the District for water resource planning, as one of the criteria used for evaluating water use permit applications, and for the design, construction and use of surface water management systems.

Established MFLs are key components of resource protection, recovery and regulatory compliance, as Section 373.0421(2) F.S., requires the development of a recovery or prevention strategy for water bodies “[i]f the existing flow or level in a water body is below, or is projected to fall within 20 years below, the applicable minimum flow or level established pursuant to S. 373.042.” Section 373.0421(2)(a), F.S., requires that recovery or prevention strategies be developed to: "(a) [a]chieve recovery to the established minimum flow or level as soon as practicable; or (b) [p]revent the existing flow or level from falling below the established minimum flow or level." Periodic reevaluation and, as necessary, revision of established minimum flows and levels are required by Section 373.0421(3), F.S.

Minimum flows and levels are to be established based upon the best information available, and when appropriate, may be calculated to reflect seasonal variations (Section 373.042(1), F.S.). Also, establishment of MFLs is to involve consideration of, and at the governing board or department’s discretion, may provide for the protection of nonconsumptive uses (Section 373.042(1), F.S.). Consideration must also be given to "…changes and structural alterations to watersheds, surface waters and aquifers, and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer…", with the requirement that these considerations shall not allow significant harm caused by withdrawals (Section 373.0421(1)(a), F.S.). Sections 373.042 and 373.0421 provide additional information regarding the prioritization and scheduling of minimum flows and levels, the independent scientific review of scientific or technical data, methodologies, models and scientific and technical assumptions employed in each model used to establish a minimum flow or level, and exclusions that may be considered when identifying the need for MFLs establishment.

The Florida Water Resource Implementation Rule, specifically Rule 62-40.473, Florida Administrative Code (F.A.C.), provides additional guidance for the establishment of MFLs, requiring that "…consideration shall be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic and wetlands ecology, including: a) Recreation in and on the water; b) Fish and wildlife habitats and the passage of fish; c) estuarine resources; d) Transfer of detrital material; e) Maintenance of freshwater storage and supply; f) Aesthetic and scenic attributes; g) Filtration and absorption of nutrients and other pollutants; h) Sediment loads; i) Water quality; and j) Navigation."

Rule 62-40.473, F.A.C., also indicates that "[m]inimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area as provided in Section 373.042(1), F.S." It further notes that, “…a minimum flow or level need not be expressed as multiple flows or levels if other resource protection tools, such as reservations implemented to protect fish and wildlife or public health and safety, that provide equivalent or greater protection of the hydrologic regime of the water body, are developed and adopted in coordination with the minimum flow or level.” The rule also includes provision addressing: protection of MFLs during the construction and operation of water resource projects; the issuance of permits pursuant to Section 373.086 and Parts II and IV of Chapter 373, F.S.; water shortage declarations; development of recovery or prevention strategies, development and updates to a minimum flow and level priority list and schedule, and peer review for MFLs establishment.

Development of Minimum Lake Levels in the Southwest Florida Water Management District

Programmatic Description and Major Assumptions

Since the enactment of the Florida Water Resources Act of 1972 (Chapter 373, F.S.), in which the legislative directive to establish MFLs originated, and following subsequent modifications to this directive and adoption of relevant requirements in the Water Resource Implementation Rule, the District has actively pursued the adoption, i.e., establishment of MFLs for priority water bodies. The District implements established MFLs primarily through its water supply planning, water use permitting and environmental resource permitting programs, and through the funding of water resource and water supply development projects that are part of a recovery or prevention strategy. The District's MFLs program addresses all relevant requirements expressed in the Florida Water Resources Act and the Water Resource Implementation Rule.

A substantial portion of the District's organizational resources has been dedicated to its MFLs Program, which logistically addresses six major tasks: 1) development and reassessment of methods for establishing MFLs; 2) adoption of MFLs for priority water bodies (including the prioritization of water bodies and facilitation of public and independent scientific review of MFLs and methods used for their development); 3) monitoring and MFLs status assessments, i.e., compliance evaluations; 4) development and implementation of recovery strategies; 5) MFLs compliance reporting; and 6) ongoing support for minimum flow and level regulatory concerns and prevention strategies. Many of these tasks are discussed or addressed in this report for Lake Hancock; additional information on all tasks associated with the District's MFLs Program is summarized by Hancock et al. (2010).

The District's MFLs Program is implemented based on three fundamental assumptions. First, it is assumed that many water resource values and associated features are dependent upon and affected by long-term hydrology and/or changes in long-term hydrology. Second, it is assumed that relationships between some of these variables can be quantified and used to develop significant harm thresholds or criteria that are useful for establishing MFLs. Third, the approach assumes that alternative hydrologic regimes may exist that differ from non-withdrawal impacted conditions but are sufficient to protect water resources and the ecology of these resources from significant harm.

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology and human-use values associated with water resources (e.g., see reviews and syntheses by Postel and Richter 2003, Wantzen et al. 2008, Poff et al. 2010, Poff and Zimmerman 2010). This information has been used by the District and other water management districts within the state to identify significant harm thresholds or criteria supporting development of MFLs for hundreds of water bodies, as summarized in the numerous publications associated with these efforts (e.g., SFWMD 2000, 2006b, Flannery et al. 2002, SRWMD 2004, 2005, Neubauer et al. 2008, Mace 2009).

With regard to the assumption associated with alternative hydrologic regimes, consider a historic condition for an unaltered river or lake system with no local groundwater or surface water withdrawal impacts. A new hydrologic regime for the system would be associated with each increase in water use, from small withdrawals that have no measurable effect on the historic regime to large withdrawals that could substantially alter the regime. A threshold hydrologic regime may exist that is lower or less than the historic regime, but which protects the water resources and ecology of the system from significant harm. This threshold regime could conceptually allow for water withdrawals, while protecting the water resources and ecology of the area. Thus, MFLs may represent minimum acceptable rather than historic or potentially optimal hydrologic conditions.

Consideration of Changes and Structural Alterations and Environmental Values

When establishing MFLs, the District considers "…changes and structural alterations to watersheds, surface waters and aquifers, and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer…" in accordance with Section 373.0421(1)(a), F.S. Also, as required by statute, the District does not establish MFLs that would allow significant harm caused by withdrawals when considering the changes, alterations and their associated effects and constraints. These considerations are based on review and analysis of best available information, such as water level records, environmental and construction permit information, water control structure and drainage alteration histories, and observation of current site conditions.

When establishing, reviewing or implementing MFLs, considerations of changes and structural alterations may be used to:

- adjust measured flow or water level historical records to account for existing changes/alterations;
- model or simulate flow or water level records that reflect long-term conditions that would be expected based on existing changes/alterations and in the absence of measurable withdrawal impacts;
- develop or identify significant harm standards, thresholds and other criteria;
- aid in the characterization or classification of lake types or classes based on the changes/alterations;

- evaluate the status of water bodies with proposed or established MFLs (i.e., determine whether the flow and/or water level are below, or are projected to fall below the applicable minimum flow or level); and
- support development of lake guidance levels (described in the following paragraph).

The District has developed specific methodologies for establishing minimum flows or levels for lakes, wetlands, rivers, estuaries and aquifers, subjected the methodologies to independent, scientific peer-review, and incorporated the methods for some system types, including lakes, into its Water Level and Rates of Flow Rule (Chapter 40D-8, F.A.C.). The rule also provides for the establishment of guidance levels for lakes, which serve as advisory information for the District, lakeshore residents and local governments, or to aid in the management or control of adjustable water level structures.

Information regarding the development of adopted methods for establishing minimum and guidance lake levels is included in Southwest Florida Water Management District (1999a, b) and Leeper et al. (2001). Additional information relevant to developing lake levels is presented by Schultz et al. (2004), Carr and Rochow (2004), Caffrey et al. (2006, 2007), Carr et al. (2006), Hancock (2006), Hoyer et al. (2006), Leeper (2006), Hancock (2006, 2007) and Emery et al. (2009). Independent scientific peer-review findings regarding the lake level methods are summarized by Bedient et al. (1999), Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

For lakes, methods have been developed for establishing minimum levels for systems with fringing cypress-dominated wetlands greater than 0.5 acre in size, and for those without fringing cypress wetlands. Lakes with fringing cypress wetlands where water levels currently rise to an elevation expected to fully maintain the integrity of the wetlands are classified as Category 1 Lakes. Lakes with fringing cypress wetlands that have been structurally altered such that lake water levels do not rise to levels expected to fully maintain the integrity of the wetlands are classified as Category 2 Lakes. Lakes with less than 0.5 acre of fringing cypress wetlands are classified as Category 3 Lakes.

Categorical significant change standards and other available information are developed to identify criteria that are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria are used to develop recommend minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. For Category 3 lakes, six significant change standards, including a Basin Connectivity Standard, a Recreation/Ski Standard, an Aesthetics Standard, a Species Richness Standard, a Lake Mixing Standard and a Dock-Use Standard are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A.C., when establishing MFLs (Table 1).

Descriptions of the specific standards and other information evaluated to support development of minimum levels for Lake Hancock are provided in subsequent sections of this report. More general information on the standards and other information used for consideration when developing minimum lake levels is available in the documents identified in the preceding sub-section of this report.

Table 1. Environmental values identified in the state Water Resource Implementation Rule for consideration when establishing minimum flows and levels and associated significant change standards and other information used by the District for consideration of the environmental values.

Environmental Value	Associated Significant Change Standards and Other Information for Consideration
Recreation in and on the water	Basin Connectivity Standard, Recreation/Ski Standard, Aesthetics Standard, Species Richness Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Fish and wildlife habitats and the passage of fish	Cypress Standard, Wetland Offset, Basin Connectivity Standard, Species Richness Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Estuarine resources	NA[1]
Transfer of detrital material	Cypress Standard, Wetland Offset, Basin Connectivity Standard, Lake Mixing Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Maintenance of freshwater storage and supply	NA[2]
Aesthetic and scenic attributes	Cypress Standard, Dock-Use Standard, Wetland Offset, Aesthetics Standard, Species Richness Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Filtration and absorption of nutrients and other pollutants	Cypress Standard Wetland Offset Lake Mixing Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
Sediment loads	Lake Mixing Standard, Cypress Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Water quality	Cypress Standard, Wetland Offset, Lake Mixing Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Navigation	Basin Connectivity Standard, Submersed Aquatic Macrophyte Information

NA[1] = Not applicable for consideration for most priority lakes;

NA[2] = Environmental value is addressed generally by development of minimum levels base on appropriate significant change standards and other information and use of minimum levels in District permitting programs

Two minimum levels and two guidance levels are typically established for lakes. Upon completion of a public input/review process and, if necessary completion of an independent scientific review, either of which may result in modification of the levels, the levels are adopted by the District Governing Board into Chapter 40D-8, F.A.C. (see Hancock et al. 2010 for more information on the adoption process). The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), may include the following (refer to Rule 40D-8.624, F.A.C.).

- A **High Guidance Level** that is provided as an advisory guideline for construction of lake shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ten percent of the time on a long-term basis.

- A **High Minimum Lake Level** that is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis.

- A **Minimum Lake Level** that is the elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis.

- A **Low Guidance Level** that is provided as an advisory guideline for water dependent structures, information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis.

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29. The datum conversion used was derived with Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

Lake Setting and Description

Location

Lake Hancock is located in west-central Polk County, Florida within the Southwest Florida Water Management District (Figure 1). The lake extends over all or portions of Sections 31 and 32, Township 28 South, Range 25 East; Sections 01, 12 and 13 Township 29 South, Range 24 East; and Sections 04 through 09 and 16 through 21, Township 29 South, Range 25 East and is approximately centered at 27°58’16’’ latitude and -81°50’18” longitude (Figure 2).

The lake is included in the Heartland Planning Region of the District and is also located in the Southern Water Use Caution Area (SWUCA). The SWUCA encompasses approximately 5,100 square miles in all or part of 8 counties within the southern portion of the District. The SWUCA was established in 1992 to address withdrawal-related saltwater intrusion in coastal areas south of Tampa Bay, reduced flows in the Peace River and lowered lake levels in Polk and Highlands counties. In 2006, the District established several MFLs within the region and adopted a SWUCA recovery strategy (Rule 40D-80.074, F.A.C. and SWFWMD 2006) to address these water resource issues.

Lake Hancock is also located within the Central Florida Water Initiative (CFWI) Planning Area. The CFWI Planning Area consists of all of Orange, Osceola, Seminole and Polk counties and southern Lake County and is based predominately on public utility service areas in the region of central Florida where the boundaries of the District, the South Florida Water Management District (SFWMD) and the St. Johns River Water Management District (SJRWMD) converge. The CWFI Planning Area was developed to assess existing and projected water needs and water sources required to meet water demands within the planning area, while sustaining area water resources and related natural systems (SFWMD, SWFWMD and SJRWMD 2014a).

Public access to the Lake Hancock shoreline is available through the Circle B Bar Reserve, an Environmental Land Property owned and maintained by Polk County and the Southwest Florida Water Management District (Figure 2). The property, which may be accessed via State Highway 540, was acquired for wildlife and water-resource protection and for restoration of the marsh system associated with the Banana Lake outlet system, which drains to Lake Hancock. There are currently no public boat ramps on Lake Hancock, although development of a paved public boat ramp and an unpaved canoe/kayak launching area has been proposed in the conservation and recreation management (SWFWMD 2009) and land use and management (SWFMWD 2010) plans developed for the District's extensive holdings in the lake vicinity.

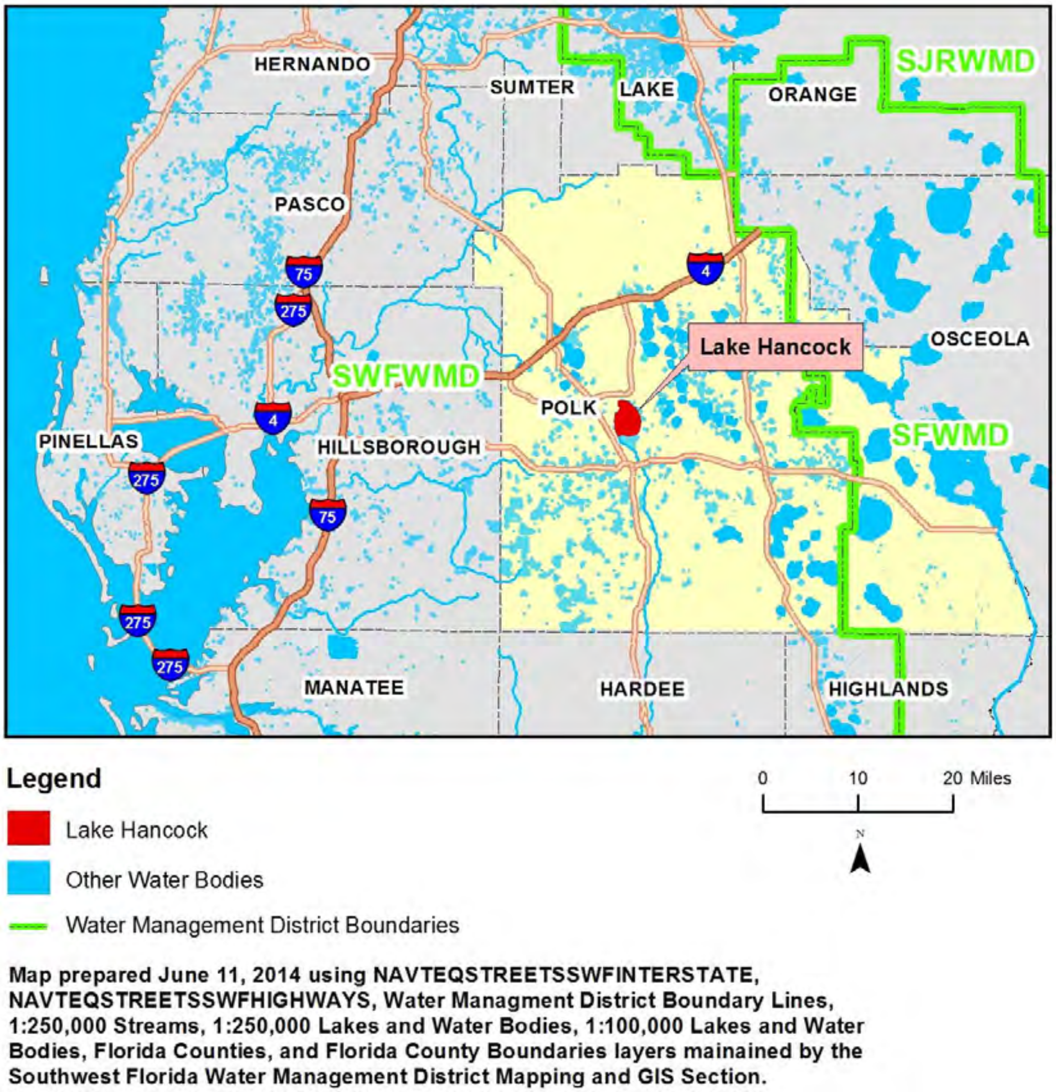


Figure 1. Location of Lake Hancock in Polk County, Florida within the Southwest Florida Water Management District (SWFWMD). Area boundaries for St. Johns River Water Management (SJRWMD) and South Florida Water Management District (SFWMD) are also shown.

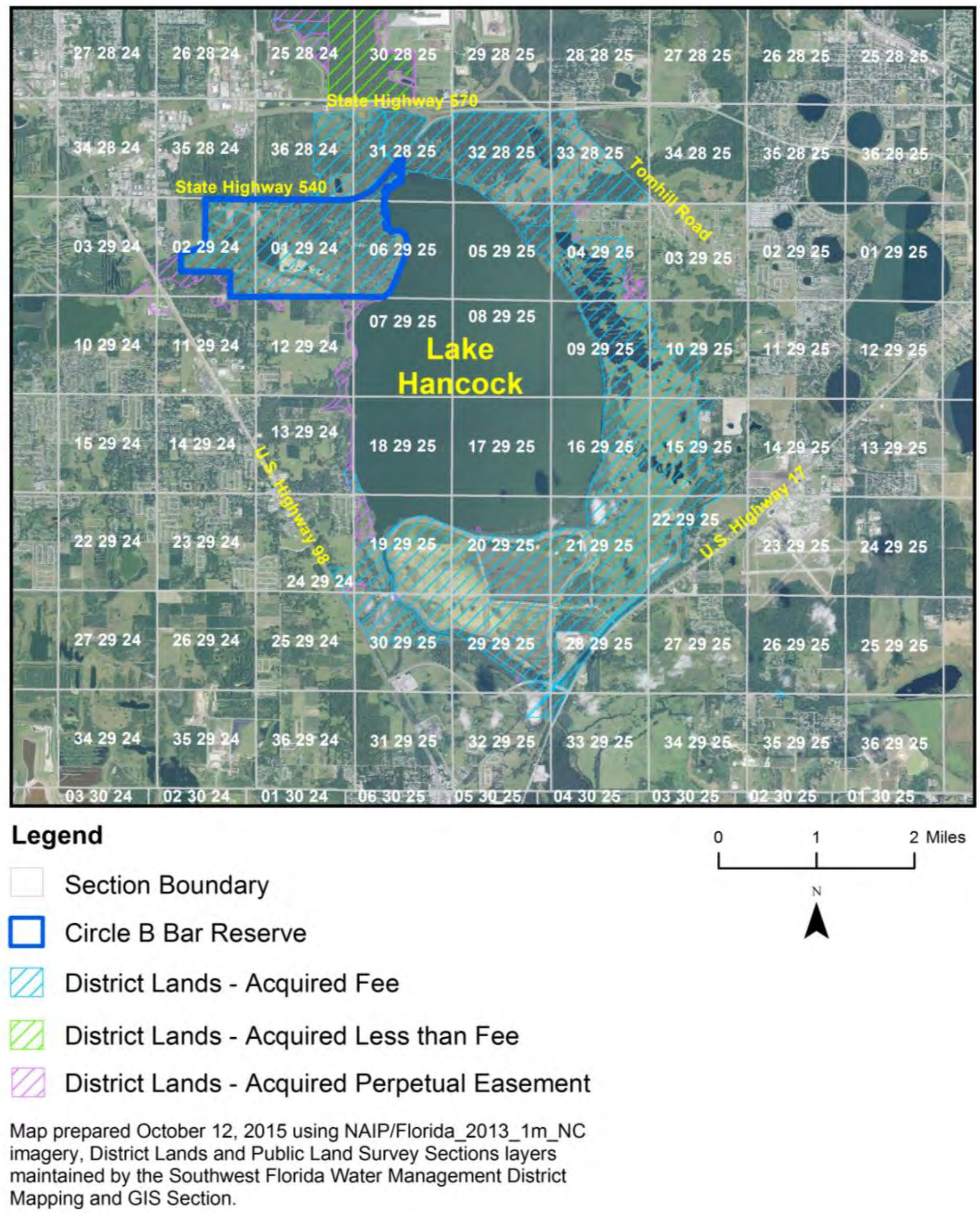


Figure 2. Location of the Circle B Bar Reserve and other District lands adjacent to Lake Hancock with numeric section, township (south) and range (east) information labeled for gridded Public Land Survey sections.

Physiography and Hydrogeology

White (1970) classified the region of central or mid-peninsular Florida containing Lake Hancock as the Polk Upland physiographic region. Brooks (1981) categorized the area around and including the lake as the Bartow Embayment in the Central Lakes

Physiographic District, and described the region as a "large erosional basin partially backfilled with the phosphatic sand and clay of the Bone Valley Formation of Pliocene age." As part of the Florida Department of Environmental Protection's Lake Bioassessment/ Regionalization Initiative, the area has also been identified as the Southwestern Flatlands lake region (Griffith et al. 1997) and described as a region containing slightly acidic to alkaline lakes that are typically eutrophic, dark-water systems.

The hydrogeology of the area starting at landsurface includes an unconsolidated surficial deposit of sand grading down to clay; a confined intermediate aquifer system (IAS) which consists of a series of thin, interbedded limestone and phosphatic clays of generally low permeability; and finally the thick carbonate Upper Floridan aquifer (UFA) (see Ellison, 2015 [updated 2017], included as Appendix A to this report)**.** The base of the surficial aquifer (SA) consists of Pliocene age clays and clayey sands that form the top of the IAS. The IAS in this area is composed of the Hawthorn group which varies in thickness from 90 to 200 feet and forms an effective confinning unit. The Hawthorn group in this area consits of the Bone Valley Member of the Peace River Formation, Peace River Formation, and the Arcadia Formation. Lithologic descriptions from borings around the lake report a high percentage of clayey sands and clay (see Figures 5 and 6 in Appendix A). Surface elevations of the Hawthorn Formation shows a surface that slopes to the east (see Figure 7 in Appendix A). Surface elevations of the Suwannee Limestone shows Lake Hancock is positioned over a high ridge that slopes away to the south and east (see Figure 8 in Appendix A). North-south and east-west cross sections show Lake Hancock is positioned in the low permeability Hawthorn Formation which attenuates and lessens the efects of drawdown from groundwater withdrawals in the Upper Floridan aquifer (see Figures 9 and 10 in Appendix A).

Bathymetry and Basin/Watershed Description and History

Lake Hancock is a meandered lake, meaning that the general boundary of the lake has been determined by a General Lake Office Survey for approximating acreage of uplands adjacent to the lake (Kenner 1961). The "Gazetteer of Florida Lakes" (Florida Board of Conservation 1969, Shafer et al. 1986) lists the size of Lake Hancock as 4,519 acres.

A topographic map of the basin generated in support of minimum levels development (Figure 3, Leeper 2008) indicates that the lake extends over 4,241 acres when the water surface is at an elevation of 97 feet above NGVD or 97 feet above mean sea level, the elevations respectively included on the 1944 United States Geological Survey 1:24,000 Auburndale and 1949 Bartow quadrangle 7.5 minute topographic maps (see Figure 4 for a more recent, photorevised Geologic Survey map image).

Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report and is also available in United States Geological Survey (1966); Foose (1981); Hammet et al. (1981); Heath and Conover (1981); Keith and Schnars, P.A. (2003); Zellars-Williams Company (1987a, as cited in Harper et al. 1999); and BCI Engineers & Scientists, Inc. (2006b).

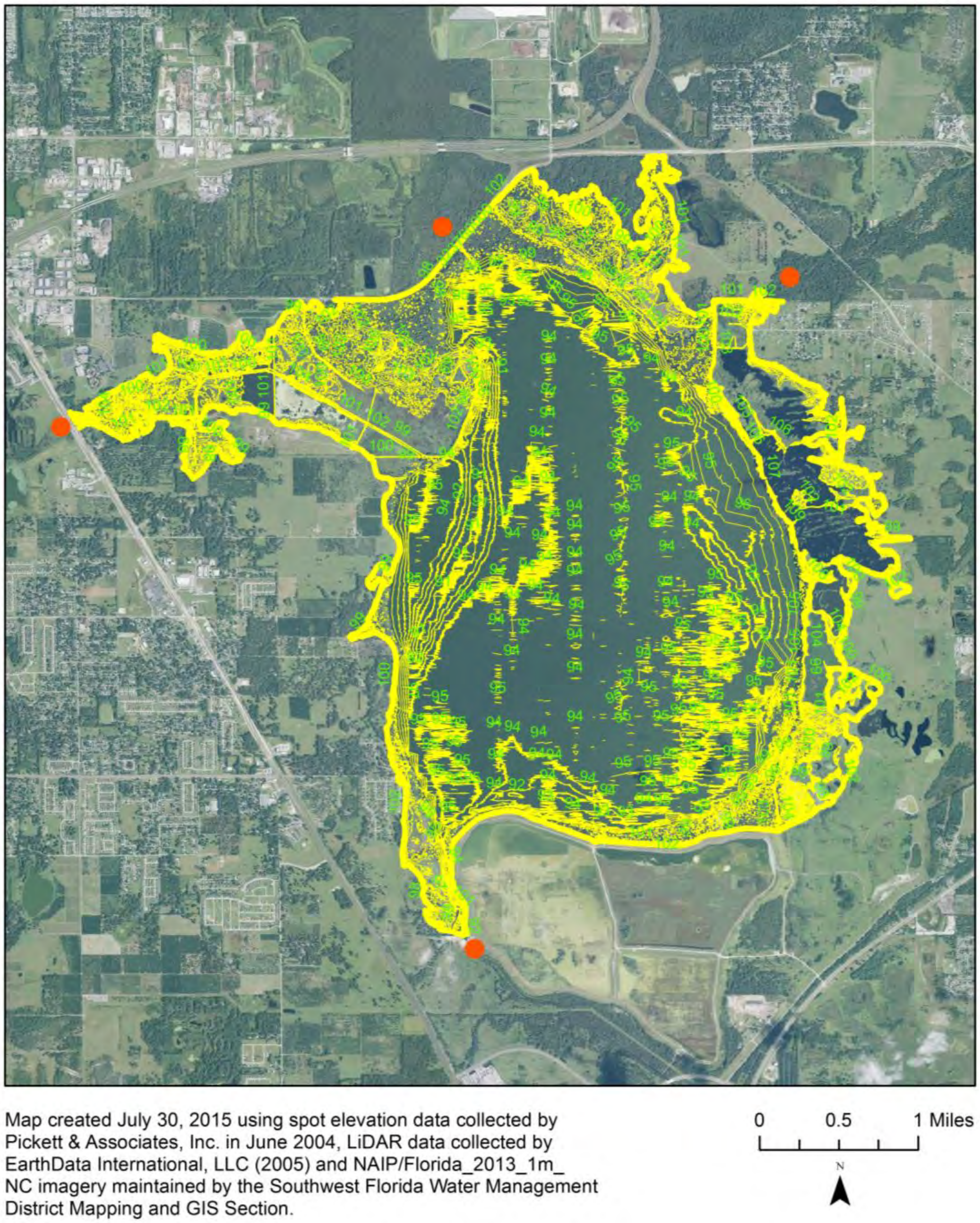


Figure 3. One-foot ground elevation (feet above NGVD) contours within the Lake Hancock basin. Orange dots identify areas where contours were truncated for mapping purposes.

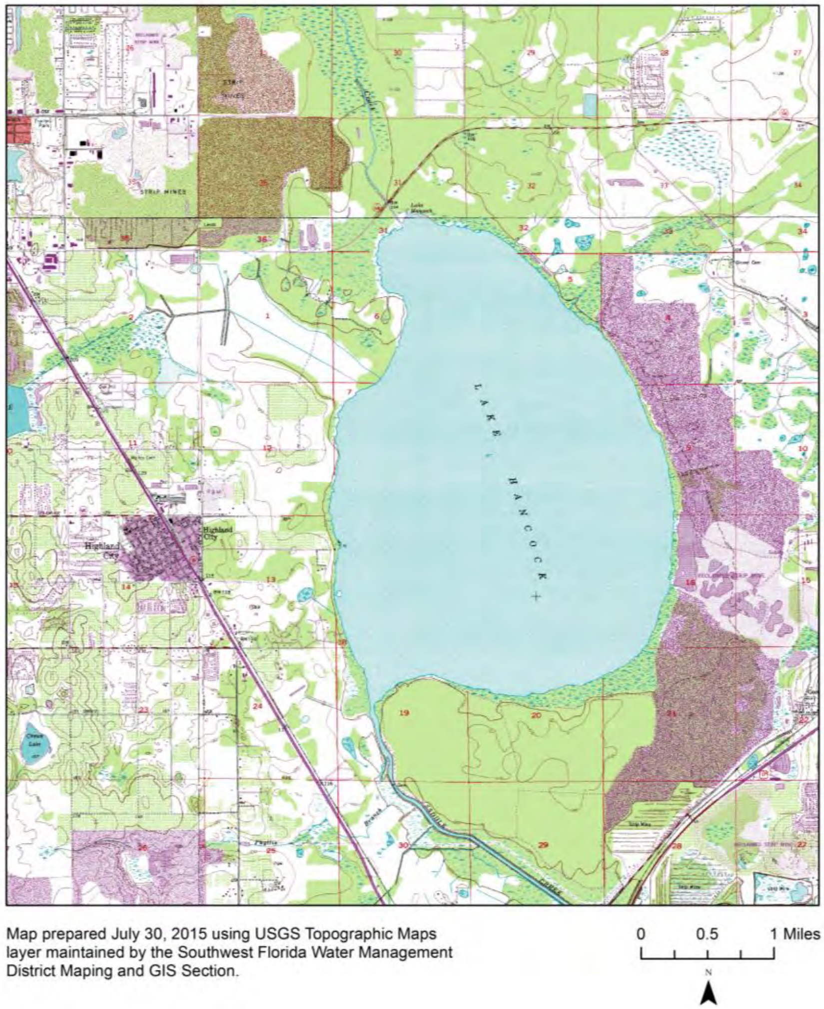


Figure 4. United States Geological Survey five-foot ground elevation contours (feet above NGVD 1929) in the vicinity of Lake Hancock.

Based on review the 2011 Florida Land Use, Cover and Forms Classification System (FLUCCS) layer maintained by the District Mapping and GIS Section, most of the land in the vicinity of Lake Hancock is classified as urban and built up, agriculture and wetlands (data not shown). The immediate lake basin includes extensive, forested and non-forested lacustrine and palustrine wetland areas (Figure 5). BCI Engineers & Scientists, Inc. (2005b) report that there are currently approximately 1,067 acres of wetlands associated with Lake Hancock and that historically, wetlands contiguous with the lake may have extended over 3,000 acres. Common obligate or facultative wet (as defined by Rule 62-340.200, F.A.C.) trees include cypress (*Taxodium* sp.), black gum (*Nyssa sylvatica* var. *biflora*), red maple (*Acer rubrum*), willow (*Salix* sp.), elm (*Ulmus* sp.), ash (*Fraxinus* sp.) and laurel oak (*Quercus laurifolia*). Common shrubs and herbaceous wetland/aquatic plants include primrose willow (*Ludwigia* sp.), Brazilian pepper (*Schinus terebinthifolius*), cattail (*Typha* sp.), pennywort (*Hydrocotyle umbellata*), pickerelweed (*Pontederia cordata*), duck potato (*Sagittaria lancifolia*), spatterdock (*Nuphar luteum*), water hyacinth (*Eichhornia crassipes*) and water lettuce

(*Pistia stratiotes*) (BCI Engineers & Scientists, Inc. 2005, Zellars-Williams Company 1987c, personal observation).

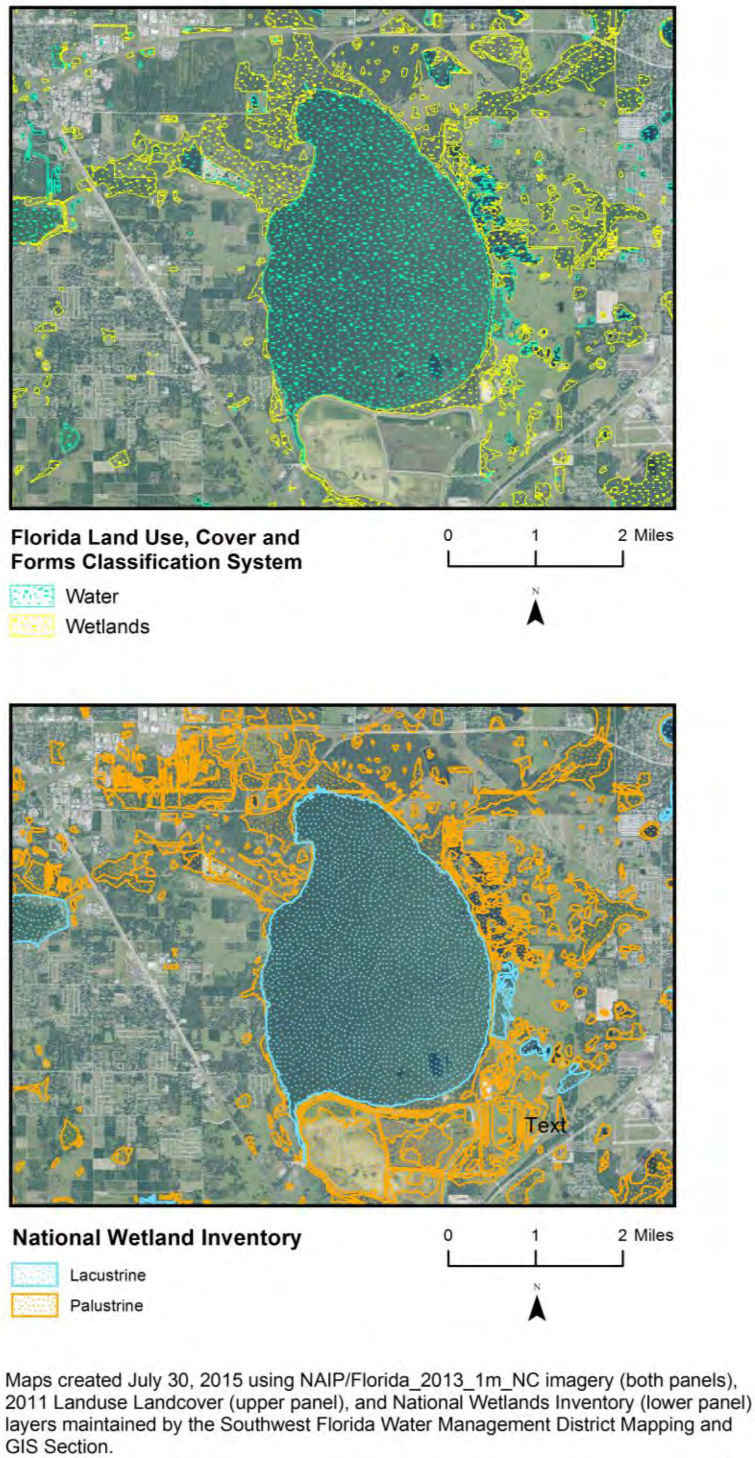


Figure 5. Lake and wetland areas in the Lake Hancock vicinity based on 2011 Florida Land Use, Cover and Forms Classification System Classification data (upper panel) and National Wetland Inventory information (lower panel).

Lake Hancock occurs within the Saddle Creek drainage basin in the Peace River watershed, as delineated for the United States Geological Survey Hydrologic Unit Classification system (Florida Department of Environmental Protection 2004a, b). Surface water inputs to the lake include direct precipitation on the lake surface, runoff from immediately adjacent upland areas, and inflow from Saddle Creek, Lake Lena Run, the Banana Lake Overflow Canal and to a lesser extent from the Eagle Lake - Millsite Lake system (BCI Engineers & Scientists, Inc. 2005a) (Figure 6).

The Lake Hancock watershed has been extensively altered as a result of drainage modifications, agricultural activity, urban development and phosphate mining. Wharton (2007) provides information such as a historical soil survey, land-survey and other maps (Figures 7 through 10) that offer some perspective on regional conditions prior to the onset of mining activity. Significant changes during the 1940s and subsequent decades included channelization of wetland areas adjacent to the northwest lake shore, in the vicinity of the current Banana Lake Overflow Canal basin, and construction of a canal bypassing wetlands at the mouth of Lake Lena Run. In addition, portions of the eastern and southern shores of the lake were ultimately mined and either reclaimed or used for clay settling ponds, and the upper segment of Saddle Creek was channelized.

Excavation of the lower segment of Saddle Creek between Lake Hancock and the Peace River is evident in photography of the region from 1941 (Figure 11) and was completed by the Lake Hancock Drainage District (Southwest Florida Water Management District 1991). Agricultural activity and mining in areas near the lake is also evident in 1941 aerial photographs, and based on later imagery, mining was initiated in the upper Saddle Creek floodplain near the lake inlet and adjacent to other shoreline areas of the lake in the 1950s and 1960s (Figures 12-15).

Inflows from Saddle Creek, which originates east of the City of Lakeland and enters the northern margin of the lake, include drainage from Lakes Bonny, Crago, Gibson and Parker and the Tenoroc Fish Management Area. Water may also be pumped into the conveyance system from Lake Deeson (Keith and Schnars, P.A. 2003). Lake Lena Run, which originates in Auburndale and ends at the northeastern lakeshore, includes surface drainage features that provide for conveyance from Lakes Ariana, Arietta, Dinner, Lena, and Whistler. Lakes Grassy, Sears and Spirit may also discharge into Lake Lena Run, as a result of relatively recent drainage modifications, including the installation of a pumping station at Lake Grassy (BCI Engineers & Scientists, Inc. 2005a). Inflows to Lake Hancock from Saddle Creek and Lake Lena Run historically included wastewater discharges from the City of Lakeland Waste Water Treatment Plant (from 1926 through April 1987) and effluent from two citrus processing plants and a distillery in Auburndale (Harper et al. 1999). The Banana Lake Overflow Canal, which terminates along the west shore of Lake Hancock, conveys drainage from Banana Lake, Stahl Lake, Lake Bentley and Lake Hollingsworth.

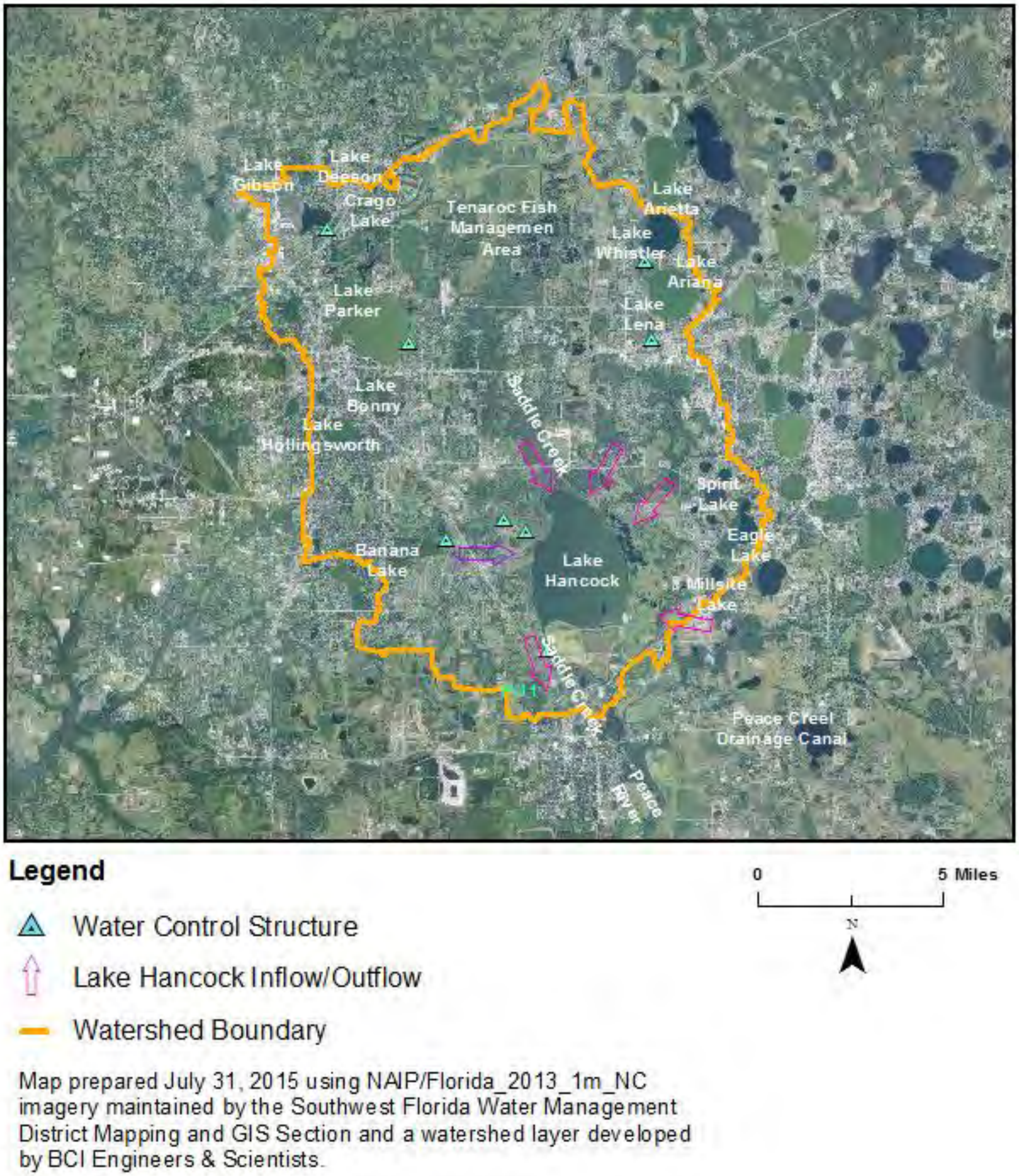


Figure 6. Lake Hancock watershed boundary, surface-flow inlets and outlets for the lake, and locations of District water control structures within the watershed, including the P-11 structure.

Figure 7. Survey map of the Lake Hancock area in 1850 by John Westcott (source: Florida Department of Environmental Protection 2008).

Figure 8. Lake Hancock area as shown on an 1856 military map prepared by J.C. Ives (source: Wharton 2007).

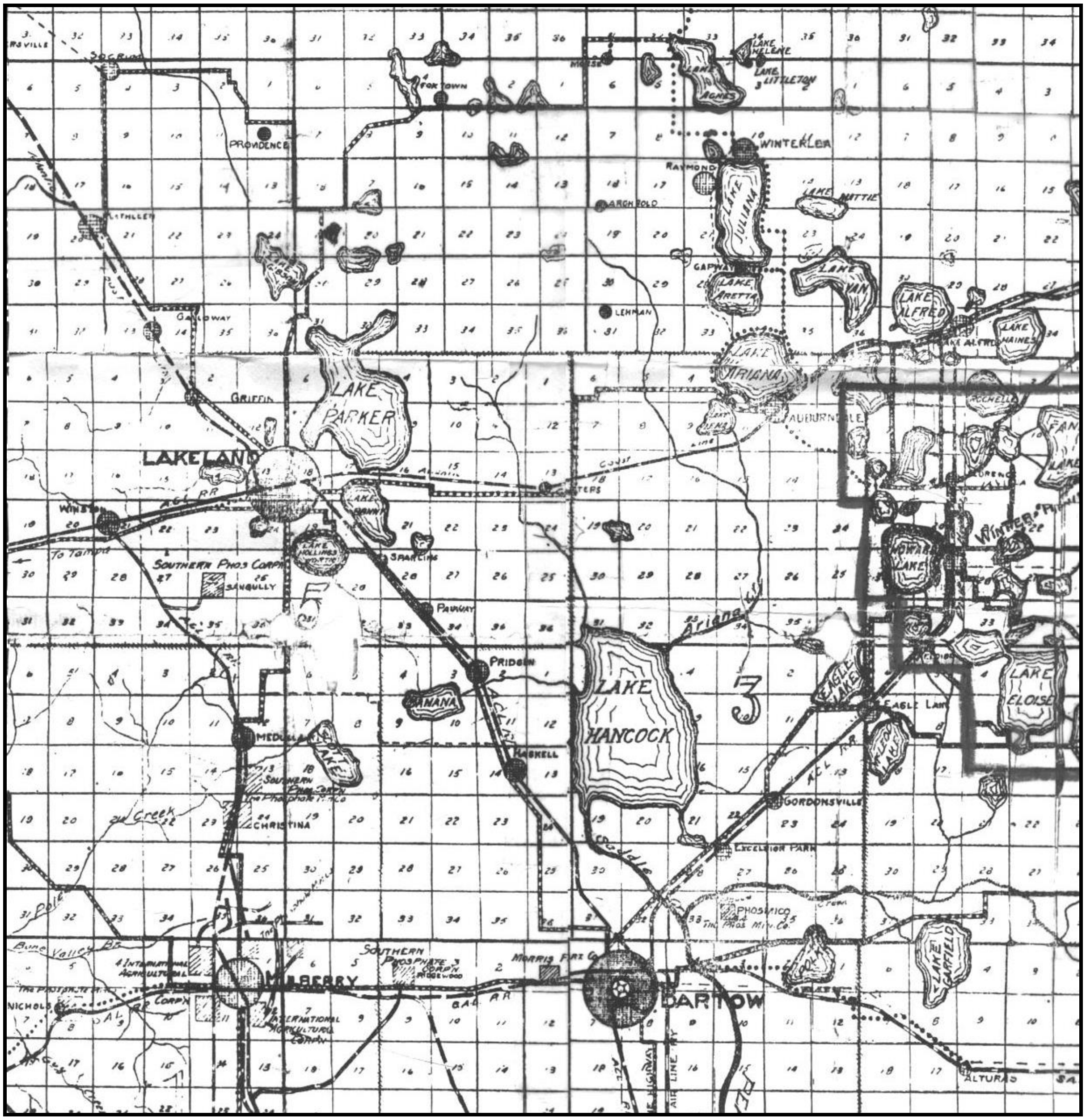


Figure 9. Image of the Lake Hancock area from a 1921 transportation map of Polk County (source: Polk County Board of County Commissioners 1921).

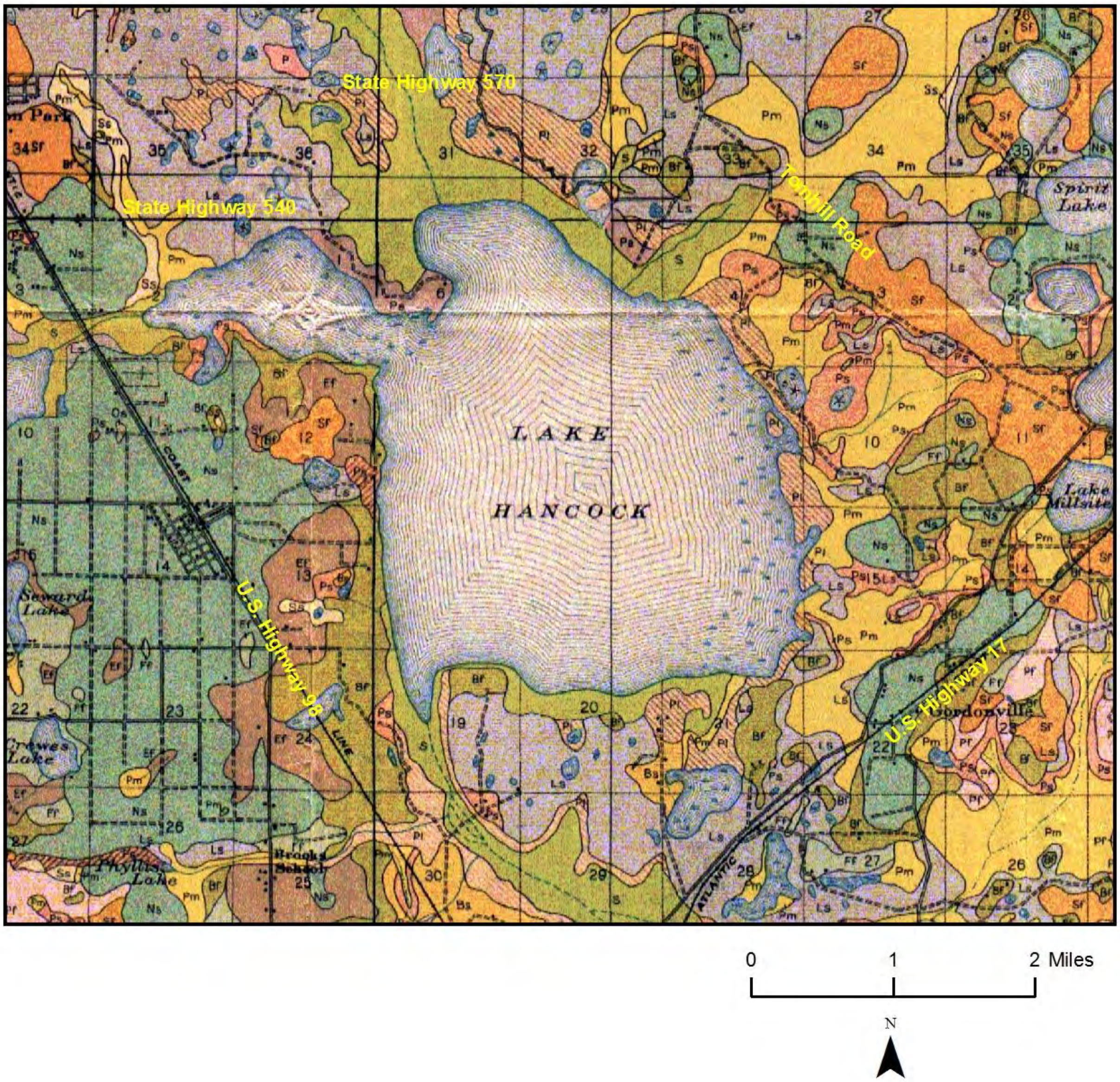


Figure 10. Image from a 1927 soil survey map of the Lake Hancock area showing the extent of basin inundation (image source: Fowler, et al. 1927, as provided by Wharton 2007).

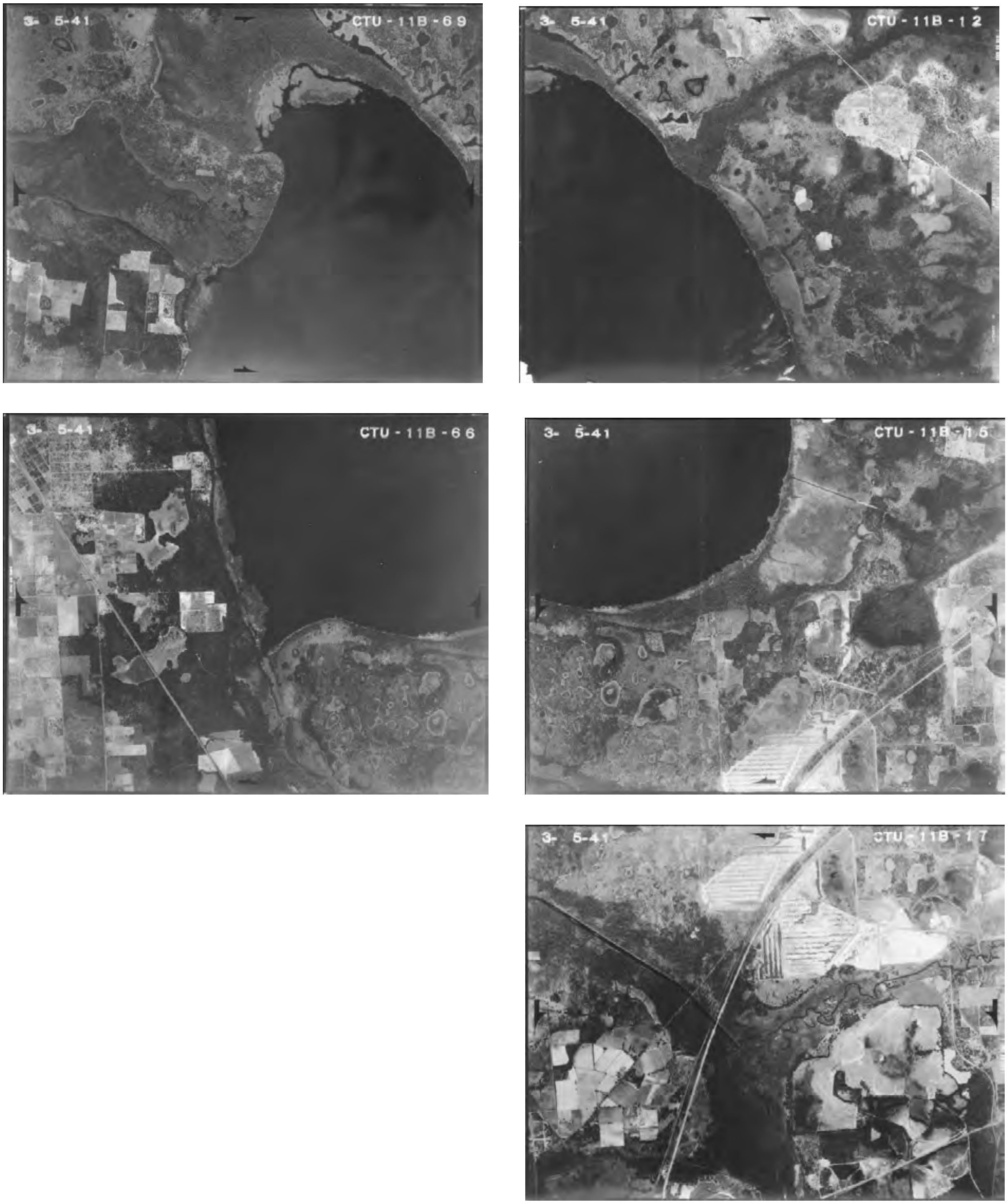


Figure 11. Aerial photographs of Lake Hancock in 1941 (United States Department of Agriculture 1941a, d, e, g and j).

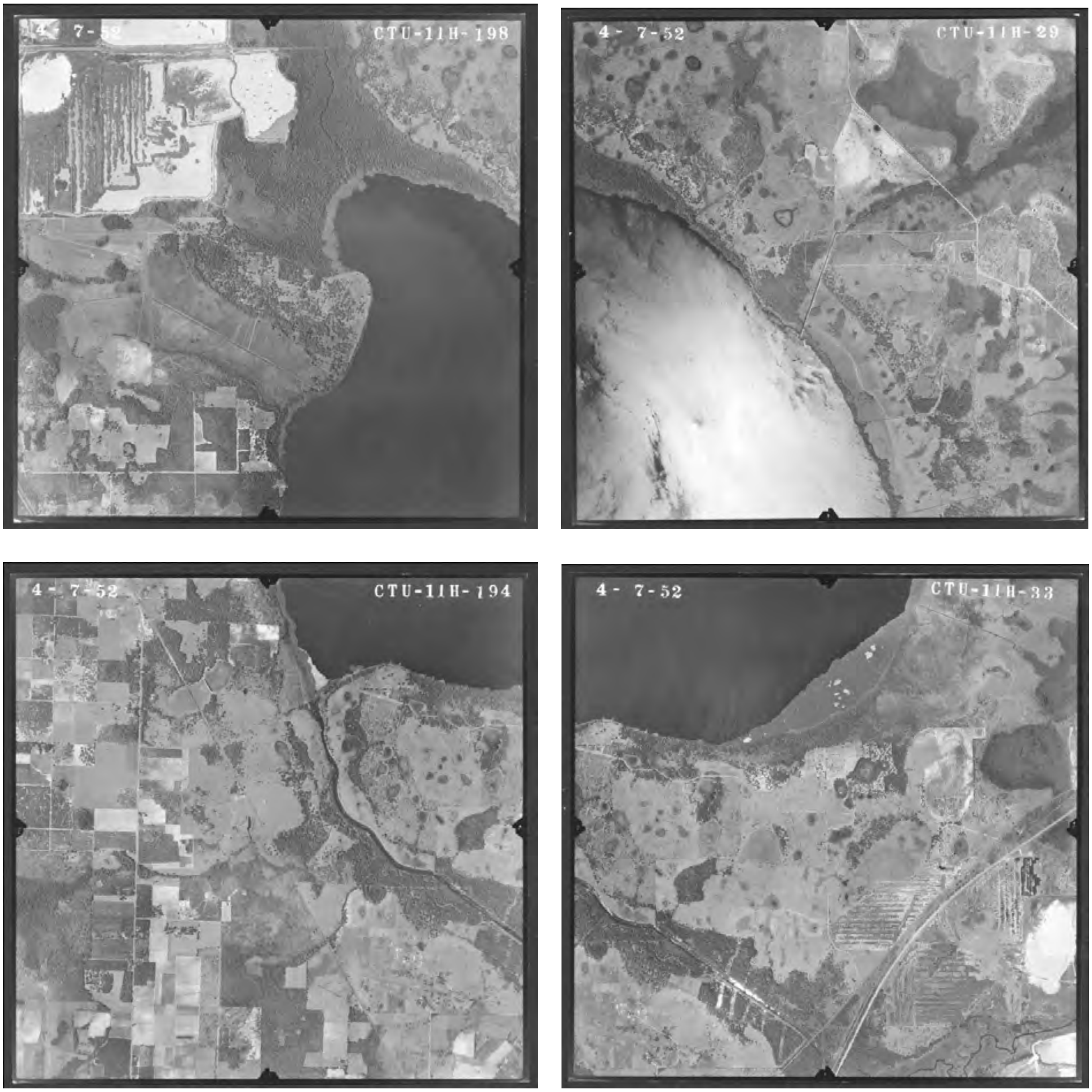


Figure 12. Aerial photographs of Lake Hancock in 1952 (United States Department of Agriculture 1952a, e, i and m).

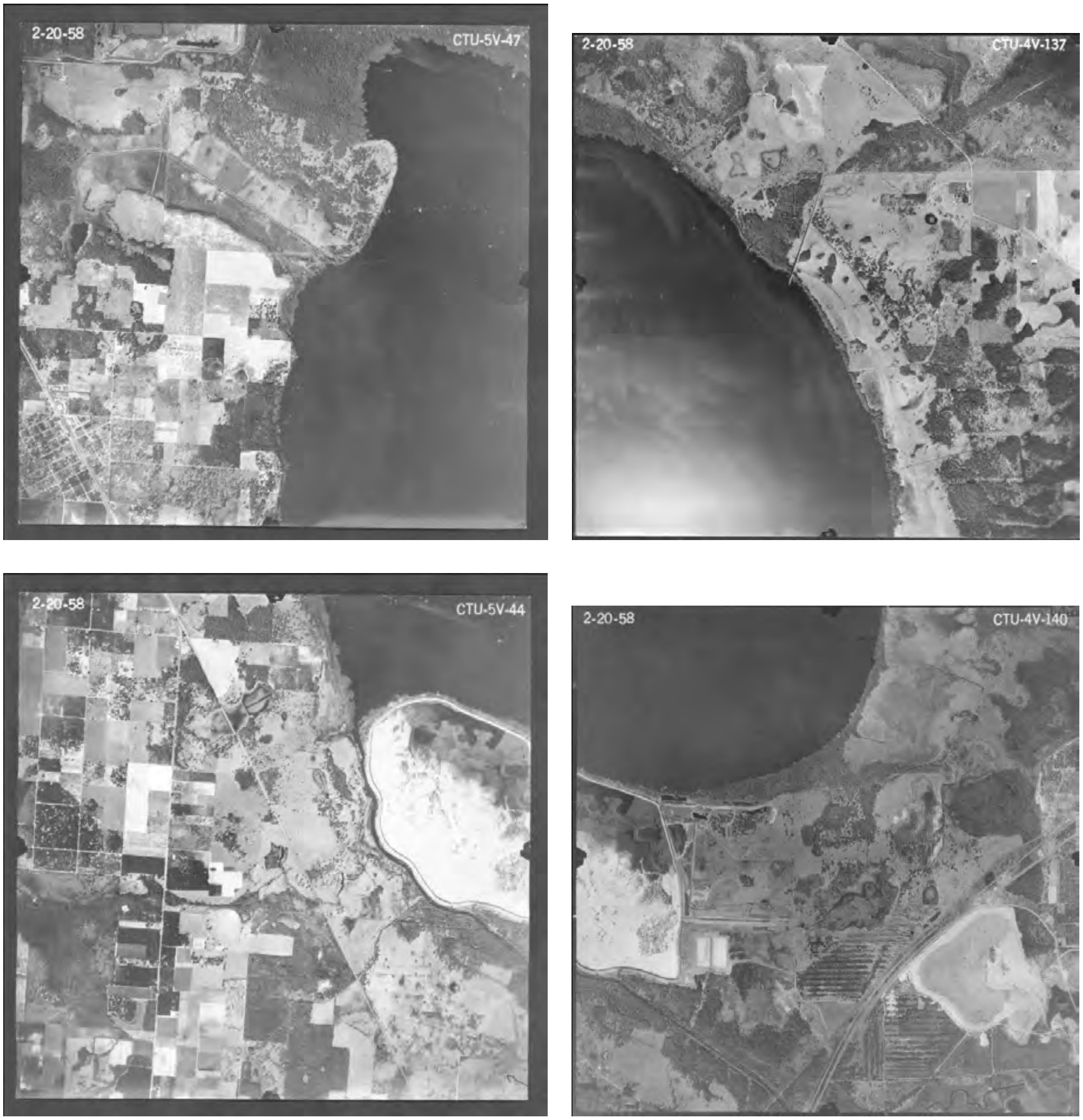


Figure 13. Aerial photographs of Lake Hancock in 1958 (United States Department of Agriculture 1958a, c, d and g).

Figure 14. Aerial photographs of Lake Hancock in 1968 (image sources: United States Department of Agriculture 1968c, f, j and m).

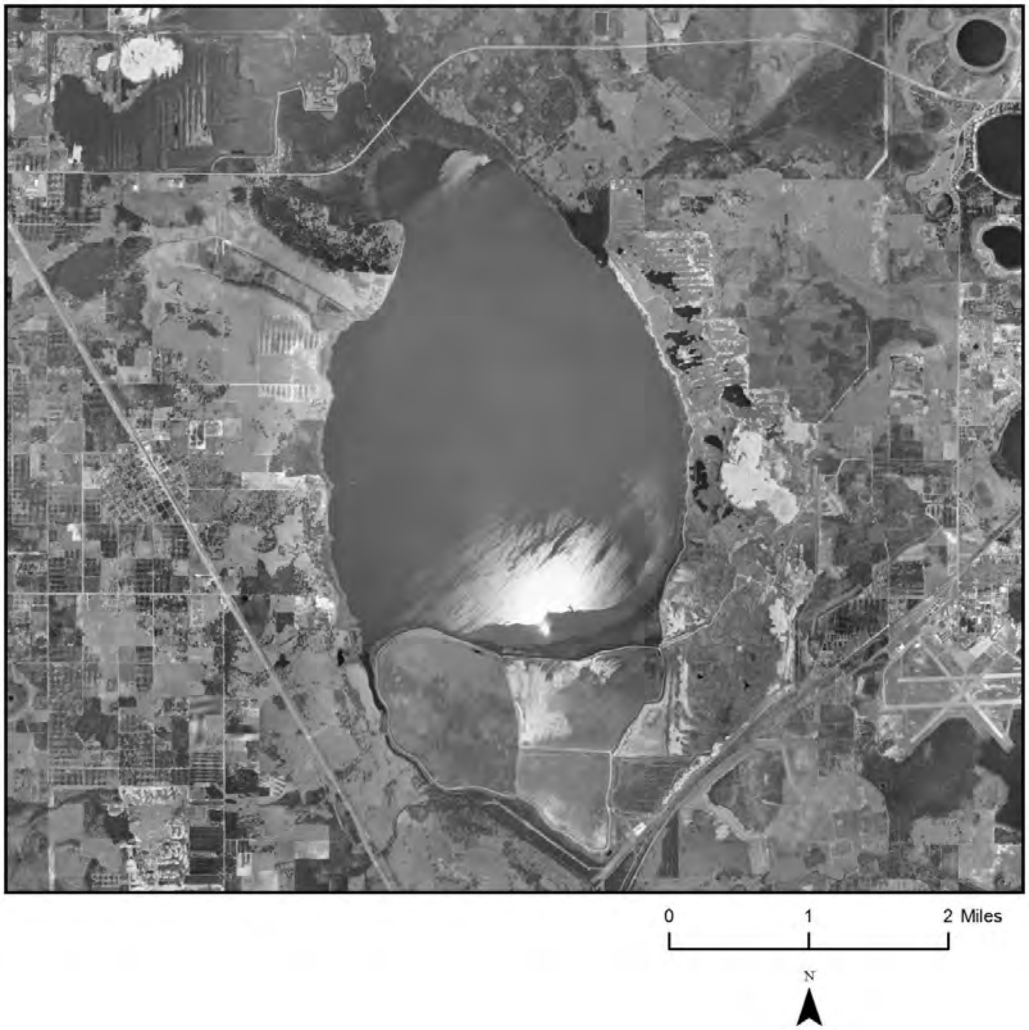


Figure 15. Aerial photograph of Lake Hancock in March 1971 (image source: Woolpert, Inc. 2005a).

Lake Hancock drains through a District water control structure (P-11) located in an excavated portion of Saddle Creek approximately 0.6-0.7 miles downstream from the southwestern lakeshore (Figure 16, see also Figure 6). The contributing watershed for flow through the P-11 structure encompasses 131 (SWFWMD 2014) to 135 (BCI Engineers and Scientists, Inc. 2005a) square miles. The Peace River originates approximately 2.3 river-miles downstream from the structure at the confluence of Saddle Creek and the Peace Creek Drainage Canal. The river extends approximately 75 miles southward to Charlotte Harbor and ultimately the Gulf of Mexico.

The current P-11 structure replaced an operable concrete and steel sheet pile weir/structure of the same name that was completed in August 1963 (Hammet et al. 1981) for the Peace River Valley Water Conservations and Drainage District. The previous P-11 structure was preceded by a concrete and timber-pile weir at the site that was used for controlling lake water levels. Construction of the current P-11 structure was initiated by a contractor for the District on November 14, 2011, was manually operational in May 2013, and was first used for conveyance on August 5, 2013. The District provided final acceptance of the structure on October 17, 2013. The structure became remotely operable on January 15, 2014.

The P-11 structure consists of an earthen embankment, a concrete spillway and a three-bay concrete structure with steel sheet pile driven to hard lime rock. Two of the structure bays include roller gates measuring 20 ft. x 10 ft. with an invert elevation of 92.0 feet above NGVD29 and a top-gate elevation of 102.0 feet NGVD29. When lifted to their maximum height, the bottom of the roller gates will clear elevation 106.0 feet above NGVD29. The third structure bay includes two weir gates, each measuring 10 feet. x 4 feet, with an invert elevation of 96.0 feet above NGVD29 when gates are fully open and a crest elevation of 100.0 feet above NGVD29 when the gates are fully closed. Riprap has been placed upstream and downstream of the structure to help control erosion.

Installation of the current P11 structure was initiated as part of the Lake Hancock Lake Level Modification Project. The structure P-11 replacement project, which was completed in 2014, was implemented to support increasing water levels in Lake Hancock to approximate levels that occurred prior to the substantial alterations associated with mining and channelization of the lake outlet, and to allow for storage of water that can be released to Saddle Creek to support recovery of minimum flow established for the upper Peace River as part of the SWUCA Recovery Strategy (SWFWMD 2006). Another associated project, the Lake Hancock Outfall Treatment System Project, involves construction and use of a wetland treatment system to improve water quality, especially nitrogen concentrations, in water discharged from the lake into Saddle Creek. The project, which was also completed in 2014, is intended to improve water quality throughout the extent of the Peace River and its receiving waters in Charlotte Harbor.

Figure 16. Aerial photograph, looking southward, of the District's P-11 structure in Saddle Creek on September 27, 2013 (Southwest Florida Water Management District files).

Hydrology

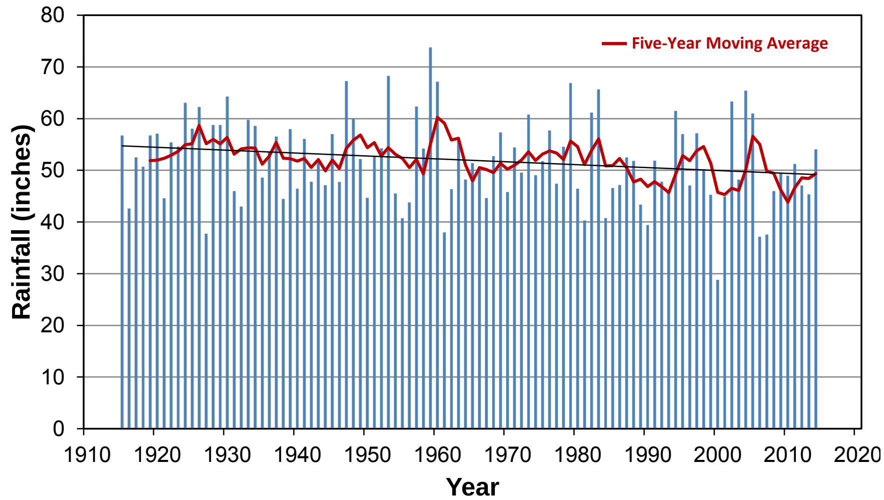
Climate and Rainfall

The climate of west-central Florida, where Lake Hancock occurs, may be characterized as humid subtropical, with warm wet summers and mild winter conditions. Local weather patterns are strongly influenced by the Gulf of Mexico, which moderates winter and summer temperatures. Mean annual air temperature for the City of Lakeland is 73 F with mean monthly temperatures ranging from around 61 to 83 F, and daily value frequently exceeding 90 F during summer and occasionally dropping below freezing during winter (Spechler and Kroening 2007).

Area-weighted regional records tabulated by the District using NEXRAD (Next-Generation Radar) and other data obtained from the National Weather Service indicate that annual rainfall in Polk County ranged from 28.8 to 73.8 inches and averaged 51.9 inches for the 100-year period from 1915 through 2014 (Figure 14, upper panel). On an annual basis, rainfall for this period was typically highest during the months of June through September (Figure 14, lower panel), likely as a result of the significant rainfall events that may be associated with convective and tropical storms that occur during these wet-season months. Evapotranspiration rates for a 5.5-year period reportedly ranged from 34.0 to 40.2 inches per year in eastern Polk County (Spechler and Kroening (2007) and annual evaporation rates of 47 to 59 inches are reported for shallow, central Florida lakes (e.g., see Henderson 1983, Schiffer 1998, Swancar et al. 2000, Metz and Sacks 2003).

Polk County rainfall exhibits a slight declining, based on ordinary least squares regression analysis of the 100-year record. Stronger, shorter-term trends are, however, apparent in the record, especially when annual values are aggregated as moving-average values (see Figure 14, upper panel). On a more regional scale, Basso (2010) reports a declining trend in area rainfall for the past several decades based on data collected at the Brooksville (Hernando County), Inverness (Citrus County) and Ocala (Marion County) National Weather Service stations, and notes that a regional decline in rainfall after 1970 corresponds to a change in the Atlantic Multidecadal Oscillation cycle from a warm (wet) to a cool (dry) period.

A plot of annual departure from the long-term average annual rainfall in Polk County provides another means for identifying periods of above or below average area rainfall. Many years in the 1920s, for example, were relatively wet, as was the four-year period from 1957 through 1960, during which annual average rainfall ranged up to 21.3 inches above the long-term average (Figure 15). Below average annual rainfall has been common in Polk County during many of the past twenty-five years, i.e. from 1990 through 2014) (Figure 15).



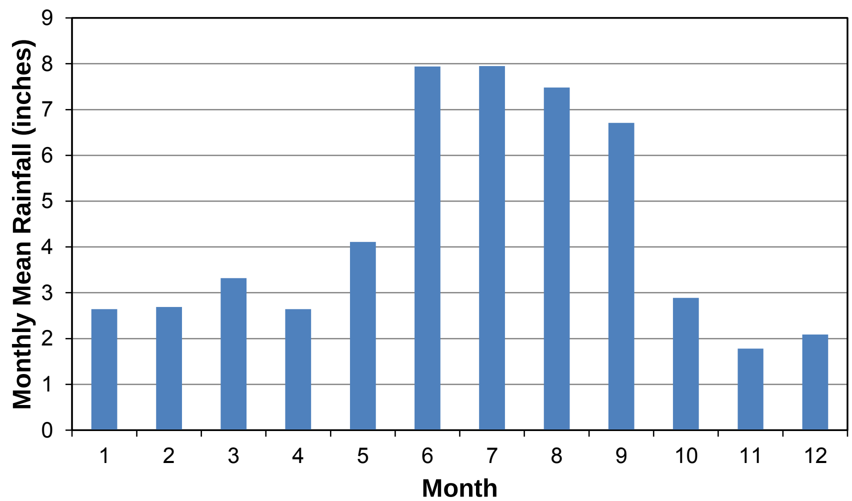


Figure 14. Area-weighted annual (upper panel) and monthly mean (lower panel) rainfall for Polk County between 1915 and 2014 (data source: Southwest Florida Water Management District Rainfall Data Summaries web page at http://www.swfwmd.state.fl.us/data/hydrologic/rainfall_data_summaries**.**

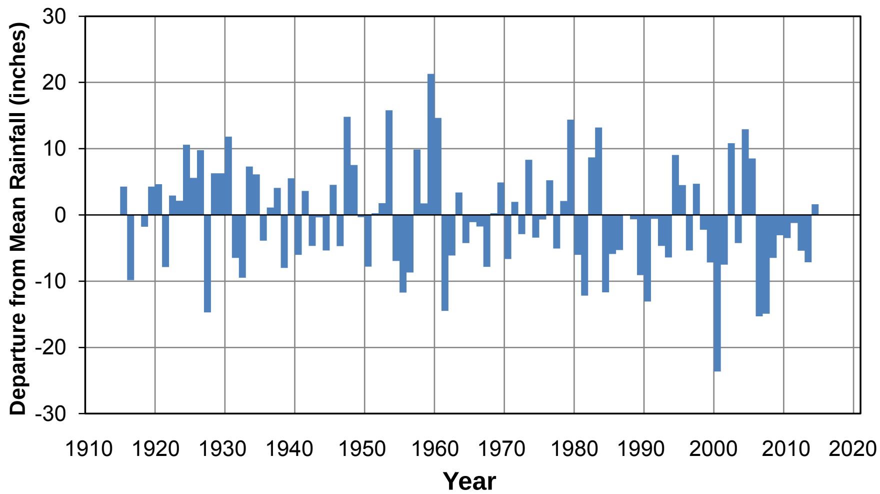


Figure 15. Annual departure from the mean annual rainfall of 51.9 inches for Polk County from 1915 through 2014.

Water Level (Lake Stage) Record

Daily Lake stage data, i.e., surface water elevations for Lake Hancock are available from the District's Water Management Information System for the period from October 23, 1958 through the present date. The Water Management Information System includes stage measurements collected by the United States Geological Survey and District staff from through September 24, 2002 at the United States Geological Survey Station number 02294462, which is named Lake Hancock (USGS) and assigned a Site Identification Number of 24760 in the District Water Management Information System. Sporadic stage readings dating back to August 28, 1950 are also available for the site from the U.S. Geological Survey's Field and Water Quality Samples included in their National Water Information System database. The District Water Management Information System also includes stage records from October 7, 2002 through the present date that were recorded at a currently used site, named Lake Hancock (R), which is located on the west shore of the lake, approximately 1.9 miles north of the historic USGS gauge site. The Site Identification number for the Lake Hancock (R) gauge is 24532. The locations of sites 24760 and 24532 are shown in Figure 16.

A daily-stage record for the period from August 28, 1950 through December 31, 2014 (Figure 17) was constructed using data contained in the District's Water Management Information System and the few earlier records from the United States Geological Survey's Water-Quality database. The highest surface water elevation for the lake in the record, 101.88 feet above NGVD, occurred on September 16, 1960. The low of record, 93.98 feet above NGVD, was recorded on May 23, 1968. Harper et al. (1999) report that the low water levels in 1968 occurred following formation of a sinkhole in the lake basin. As of September 2009, the District has documented three reported sinkholes within the lake (Southwest Florida Water Management District 2009b).

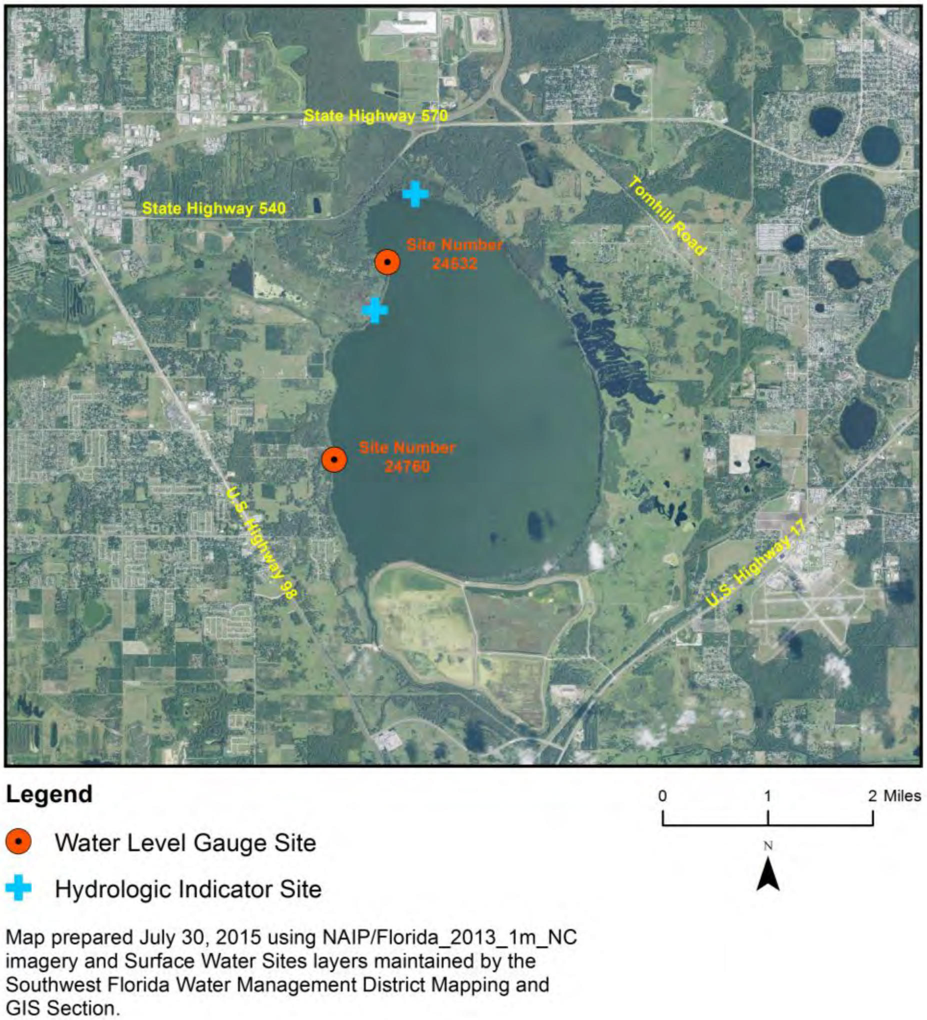


Figure 16. Locations of the current (SID or Site Identification Number 24532) and former (SID 24760) water-level gage sites in Lake Hancock.

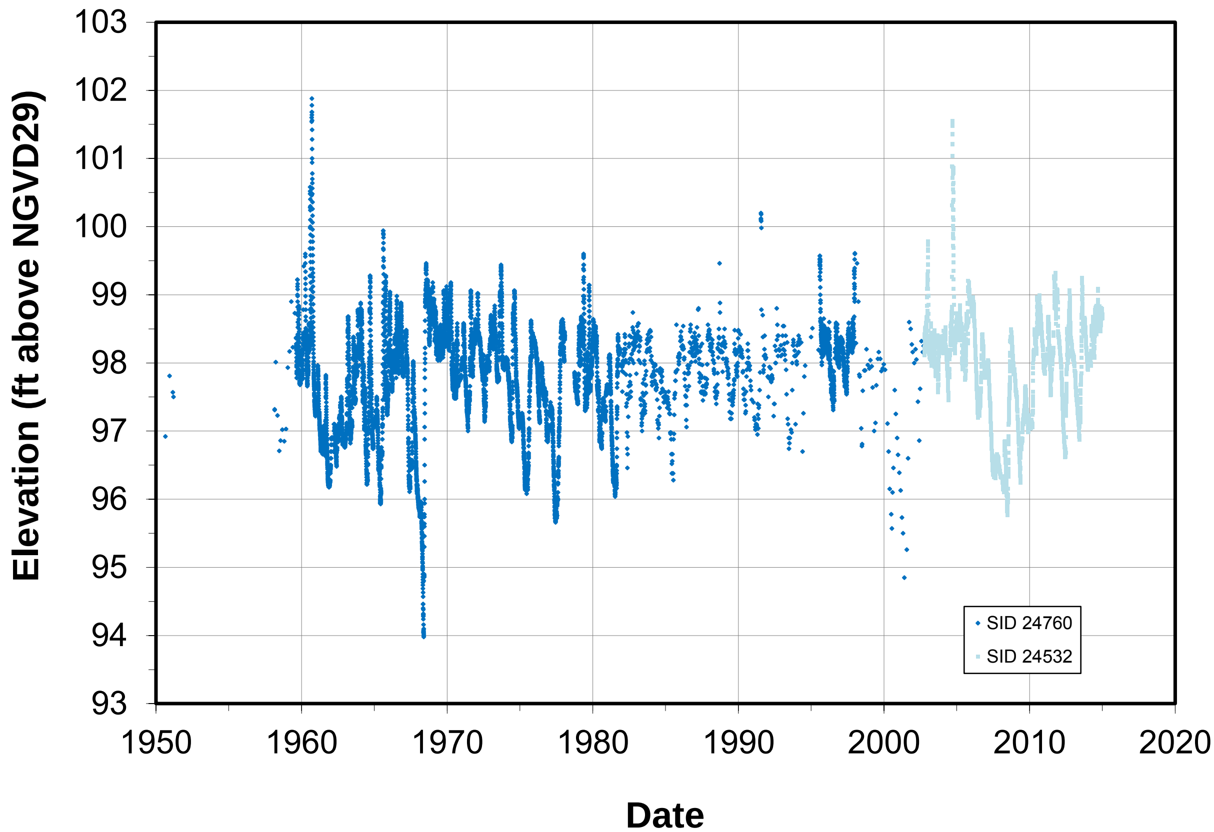


Figure 17. Daily water surface elevations for Lake Hancock from August 28, 1950 through December 31, 2014 collected at two gage sites (SID 24760 and SID 24532).

Water Use in the Lake Area and Evaluation of Withdrawal Impacts

Historical water use near Lake Hancock has been addressed in numerous investigations, including those by Stewart (1966), Kaufman (1967), Robertson and Mills (1974), Duerr and Sohm (1983), Barcelo et al. (1990), Marella (1992), and SWFWMD (2001). The effects of increasing water use, as estimated by Robertson (1974) are observable in the hydrographs of wells (Figure 18) and lakes throughout the area (see also Figures 15, 16 and 17 in Appendix A). The Coley Deep well, which is represented in Figure 18 in Appendix A, is located on the Lake Wales Ridge near Crooked Lake, while the other well included in the figure, the ROMP 60 well, is located to the west of the Ridge area where groundwater withdrawals for agriculture and mining were most significant. The hydrographs for these two wells show decreased water levels concurrent with increases in water use.

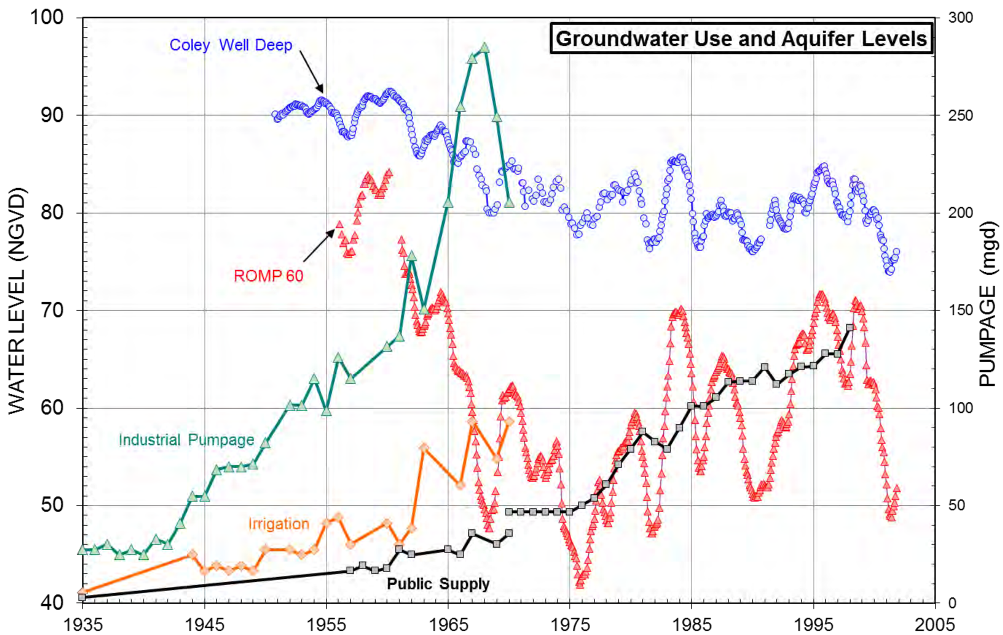


Figure 18. Early water use estimates for public supply, irrigation and industrial pumping (Robertson 1974) and hydrographs of two Upper Floridan aquifer wells (Coley Well Deep, ROMP 60) near Lake Hancock (reproduced from Figure 14 in Ellison (2015 [updated 2017]), which is included as Appendix A to this report).

Detailed water use near Lake Hancock was obtained from the District's 2013 annual estimated water use report (SWFWMD 2014a). The water use data included in these reports are primarily from the District Water Use Permitting database in the Water Management Information System. The water quantity data is derived from metered withdrawal points and from estimates applied to unmetered withdrawal points. Population data is based on population numbers given by public supply permittees on the Public Supply Annual Report forms and functional Bureau of Economic and Business, i.e., BEBR, population data. About 81 percent of the water use identified in the report is based on directly metered withdrawals. Since the total water use contains an element of estimation, the annual report is referred to as the "Estimated Water Use Report."

Surface water withdrawals from Lake Hancock may have occurred historically, but there are currently no District-permitted surface withdrawals at the lake. There are, however, numerous permitted groundwater withdrawals in the area. Individual withdrawal point locations near Lake Hancock are shown in Figure 19 and graphs depicting total water use within specified radial distances from a central point within the lake are presented in Figures 19 and 20 within Appendix A). Water use within the first mile of the central point is zero since this region is contained within the lake. Water use for the area within two miles of the central point is less than 1 mgd. At three miles, the water use ranges between 1 to 6 mgd with an average around 2 mgd. At five miles, water use ranges from 2 to 18 mgd with an average around 7 mgd. At six miles, the water use ranges from 6 to 26 mgd with an average around 12 mgd. From 2003 on water use has decreased slightly.

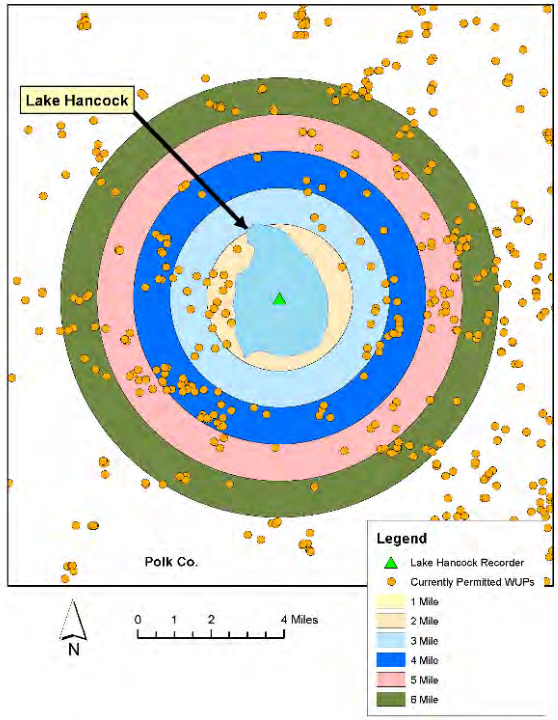


Figure 19. Currently permitted withdrawal sites for water use permits (WUPs) near Lake Hancock.

Impacts of groundwater withdrawals on the Lake Hancock area were evaluated through review of historic water levels and use of groundwater models (see Appendix A for more detailed information than is presented here). A review of long-term water levels for Lake Hancock indicated little change in long-term lake levels. This suggested that the lake has not been significantly affected by groundwater withdrawals. It is recognized, however, that the P-11 structure on the southern end of the lake has at times, been operated to retain water in the lake, and this has tended to stabilizing effect on lake water levels.

Groundwater models used to assess effects of withdrawals on Lake Hancock included the Peace River Integrated Model (PRIM; HydroGeoLogic, Inc. 2011 and 2012), the East-Central Florida Transient (ECFT) Model (SFWMD, SWFWMD and SJRWMD 2014b) and the District-wide Regulatory Model (DWRM). The three models were used for the assessment because they include slightly different conceptualizations and it was important to determine whether they would yield similar results regarding potential withdrawal effects on Lake Hancock water levels. The PRIM is a fully integrated model and the ECFT model may be described as a quasi-integrated model. These two models are transient models that use supplied rainfall and irrigation to calculate surface runoff and recharge to the water table, whereas in the DWRM, net recharge is determined externally and then applied directly to the water table.

To estimate effects of groundwater withdrawals on the SA and UFA, each model was run with a 50 percent reduction in groundwater withdrawals. This approach was used to minimize potential problems that can occur with groundwater flow models when withdrawals are completely removed from simulations, including the prediction of water levels that are above land surface. These types of issues are especially of concern when a model is not calibrated to a “no-pumping” condition. The magnitude of water level recovery in the model runs was interpreted as the drawdown or change in water levels due to pumping a quantity equivalent to the 50 percent reduced pumping quantity. To estimate drawdown or change associated with all pumping, i.e., 100 percent of the current pumping quantities, values predicted for the 50 percent withdrawal reduction scenarios were doubled.

With respect to the UFA, water level changes of about 6 to 7.5 feet were predicted at the center of the lake for the 50 percent reduction scenarios for all three models, yielding predicted changes of about 12 to 15 feet for current pumping rates. For the SA, the ECFT and PRIM models were generally consistent with predicted water level changes on the order of 0.5 feet or less in the eastern to northwestern portions of the lake basin for the 50% withdrawal reductions for a total change of about 0.5 to 1 feet. Areas of greatest change were in the south/southwestern portions of the basin and were generally on the order of 0.5 to 1 foot for the assessed simulations, for a total potential water level change of over 1 foot. The DWRM indicated drawdowns on the order of 0.5 feet (total estimated change of 1.0) adjacent the lake in northern portions of the basin and upwards of 2 feet (total estimated change of 4 feet) in southern portions of the basin.

Of the three models used for assessing withdrawal effects on Lake Hancock, the PRIM model was conceptualized with greater focus on lakes, and was originally developed to gain a better understanding of the hydrologic processes and interactions that affect the Peace River Basin and flows in the river. Simulations run with the PRIM model indicate that changes in groundwater pumping have little effect on Lake Hancock. The sensitivity of water levels in the lake to groundwater heads, and therefore to groundwater withdrawals, is greatest under low lake levels conditions. At median and higher lake levels, the model predicts little or no sensitivity to groundwater withdrawals at Lake Hancock. The 50% reduction in groundwater withdrawals scenario resulted in less than 0.1 ft. change in the P10 lake surface elevation (i.e. the water level equaled or exceeded ten percent of the time), the same amount of change at median lake stage, and a 0.1 ft. change in the P90 (i.e., the water level equaled or exceeded ninety percent of the time). The results from the PRIM model runs indicate that Lake Hancock is not sensitive to groundwater withdrawals.

Historical Management Levels

The Southwest Florida Water Management District has a long history of water resource protection through the establishment of lake management levels. Early efforts included adopting resolutions associated with establishing water control levels, such as the respective minimum and maximum water levels of 95.00 and 98.60 feet above mean sea level approved for Lake Hancock in 1966 (SWFWMD 1966). With the development of the Lake Levels Program in the mid-1970s, the District began establishing management levels based on hydrologic, biological, physical and cultural aspects of lake ecosystems. By 1996, management levels for nearly 400 lakes had been adopted into District rules.

Based on work conducted in the late 1970s and early 1980s (see SWFWMD 1996a), the District adopted management levels, including minimum and flood levels, for Lake Hancock in September 1980 (Table 2) and incorporated the levels into its Water Levels and Rates of Flow Rules (Chapter 40D-8, F.A.C.). As part of the work leading to the adoption of management levels, a Maximum Desirable Level of 98.50 feet above mean sea level was also developed for the lake, but was not adopted by rule. The Maximum Desirable Level and a Minimum Desirable Level of 95.00 feet above NGVD were, however, included in resolutions approved by the Board in August 1966 (Southwest Florida Water Management District 1996).

Based on changes to sections of the Florida Statutes that address minimum flows and levels in 1996 and 1997, and the development of new approaches for establishing minimum flows and levels, District Water Levels and Rates of Flow rules were modified in 2000. The modifications included incorporation of rule language addressing minimum flows and levels development and the renaming of established levels as guidance levels, as indicated for Lake Hancock in Table 2. Subsequent revisions to District rules incorporated additional rule language associated with developing minimum lake levels, and the Ten Year Flood Guidance Level for Lake Hancock and other lakes was removed from Chapter 40D-8, F.A.C. in 2007, when the Governing Board determined that flood-stage elevations should not be included in the District’s Water Levels and Rates of Flow rules. The intent of this latter action was not to discontinue development of regional and site-specific flood stage information, but rather to promote organizational efficiency by eliminating unnecessary rules. Flood stage levels for lakes will continue to be developed under the District's Watershed Management Program, but ten-year flood recurrence levels will not be incorporated into Chapter 40D-8, F.A.C. Historical and more recent flood-stage information for Lake Hancock is available in numerous published reports (e.g., United States Army Corps of Engineers 1974, SWFWMD 1976, Keith and Schnars, P.A. 2003, Arnold 2004 and BCI Engineers & Scientists, Inc. 2006d).

Starting in 1989, the District began annually developing a list of stressed lakes to support District's consumptive water use permitting program. As described in the current Water Use Permit Information Manual Part B Basis of Review incorporated by reference into the District's Consumptive Use of Water Rule (Chapter 40D-2, F.A.C.), "a stressed condition for a lake is defined to be chronic fluctuation below the normal range of lake level fluctuations." For lakes with adopted guidance levels, chronic fluctuation below the Low Level is considered a stressed condition. For lakes without adopted levels, the evaluation of stressed condition is conducted on a case-by-case basis. Lake Hancock w not included on the most current Stressed Lakes List (Kolasa 2015) nor was it previously been classified as a stressed lake.

Previously adopted guidance levels and the Maximum and Minimum Desirable Levels for Lake Hancock were developed using methods that differ from the current District approach for establishing minimum and guidance levels. The levels do not, therefore, necessarily correspond with the levels developed using current methods that are described in this report

Table 2. Previously adopted management/guidance levels for Lake Hancock.

Management Levels (as originally adopted)	**Guidance Levels (as renamed in 2000)**	**Elevation (feet above Mean Sea Level)**
Ten (10) Year Flood Warning Level	Ten Year Flood Guidance Level [a]	102.40 [a]
Minimum Flood Level	High Level [b]	99.00 [b]
Minimum Low Management Level	Low Level [b]	96.00 [b]
Minimum Extreme Low Management Level	Extreme Low Level [b]	94.00 [b]

[a] Removed from District rules in 2007.

[a] Removed from District rules in 2015.

Methods, Results and Discussion

Summary Data Used for Minimum and Proposed Guidance Levels Development

Minimum and proposed guidance Levels were developed for Lake Hancock using the methodology for Category 2 lakes described in Chapter 40D-8, F.A.C. The levels along with lake surface area for each level are listed in Table 3 along with other information used for development of the levels. Detailed descriptions of the development and use of these data are provided in subsequent sections of this report.

Table 3. Minimum and proposed guidance levels, lake stage exceedance percentiles, Normal Pool, Control Point elevation, significant change standards and associated surface areas for Lake Hancock.

	Elevation (feet above NGVD29)	Lake Area (acres)
Lake Stage Exceedance Percentiles		
Historic P10[a]	98.8	5,661
Historic P50[a]	97.6	4,390
Historic P90[a]	96.7	4,193
Period of Record P10	98.7	5,494
Period of Record P50	98.0	4,474
Period of Record P90	96.7	4,193
Normal Pool and Control Point		
Normal Pool	99.6	6,210
Control Point	92.0 to 102.0	140 to 7,065
Significant Change Standards		
Cypress Standard	97.8	4,426
Basin Connectivity Standard [b]	97.4	4,356
Recreation/Ski Standard [b]	97.4	4,356
Wetland Offset Elevation [b]	96.8	4,209
Aesthetic Standard [b]	96.7	4,193
Species Richness Standard [b]	95.3	3,895
Lake Mixing Standard [b]	90.6	1
Dock-Use Standard [b]	Not Developed	Not Applicable
Minimum and Proposed Guidance Levels		
High Guidance Level [c]	98.8 [c]	5,661
High Minimum Lake Level	98.8	5,661
Minimum Lake Level	97.6	4,390
Low Guidance Level [c]	96.7 [c]	4,193

[a] Based on a composite Historic water level that includes measured and modeled values.
[b] Developed for comparative purposes only; not used to establish minimum levels for Lake Hancock.
[c] Proposed guidance Leve were not adopted into District rules.

Bathymetry

Relationships between lake stage, inundated area and volume can be used to evaluate expected fluctuations in lake size that may occur in response to climate, other natural factors, and anthropogenic impacts such as structural alterations or water withdrawals. Long term reductions in lake stage and size can be detrimental to many of the environmental values identified in the Water Resource Implementation Rule for consideration when establishing minimum flows and levels. Stage-area-volume relationships are therefore useful for developing significant change standards and other information identified in District rules for consideration when developing minimum lake levels.

Stage-area-volume relationships were determined for Lake Hancock by building and processing a digital elevation model (DEM) of the lake basin and surrounding watershed. The DEM, represented as a triangulated irregular network (TIN) was created with ESRI® ArcMap™ version 10.1 software, including the ArcMap 3D Analyst Extension, using Light Detection and Ranging Data (LiDAR) data collected by EarthData International, LLC (2005) and maintained by the District Mapping and GIS Section, and surveyed spot elevation data collected from inundated lake areas with a survey grade fathometer and digital global positioning system equipment (Pickett & Associates 2004).

Topographic contours of the lake basin (refer to Figure 3) were developed from the TIN. Lake stage-area-volume estimates were also derived from the TIN using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ArcMap 3D Analyst Extension at one-tenth of a foot elevation change increments (selected stage-area-volume results are presented in Figure 25).

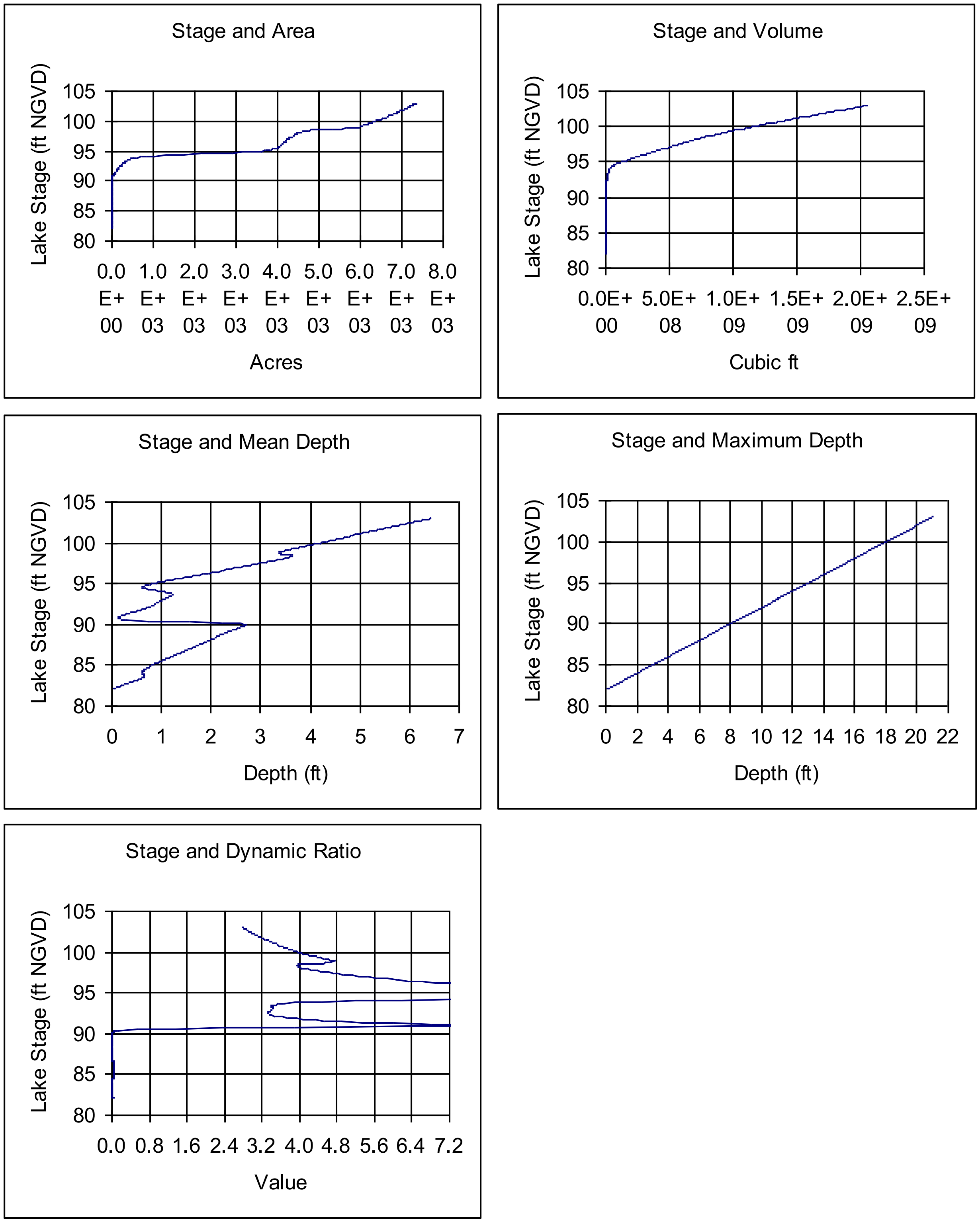


Figure 25. Lake Hancock surface area, volume, mean depth, maximum depth and dynamic ratio (basin slope) as a function of lake stage.

Classification of Lake Stage Data and Development of Exceedance Percentiles

For minimum levels determination, lake stage data are categorized as "Historic" for periods when there were no measurable impacts due to water withdrawals, and impacts due to structural alterations were similar to existing conditions. In the context of minimum levels development, "structural alterations" means man's physical alteration of the control point, or highest stable point along the outlet conveyance system of a lake, to the degree that water level fluctuations are affected. Lake stage data are categorized as "Current" for periods when there were measurable, stable impacts due to water withdrawals, and impacts due to structural alterations were stable.

Based on water-use estimates and analysis of lake stage and regional ground water fluctuations, hydrologic data collected prior to the mid-1960s for many lakes in the Lake Wales Ridge and other nearby areas in Polk and Highlands Counties may be classified as Historic data, and data collected since that period may be classified as Current data (Ellison 2002; see also Appendix A). Lake stage data for Lake Hancock measured from January 1966 through the present, i.e., through December 2014, were therefore used to calculate Current P10, P50, and P90 lake-stage percentile elevations. The Current P10 elevation, the elevation the lake water surface equaled or exceeded ten percent of the time during the current period, was 98.7 feet above NGVD29. The Current P50 elevation, the elevation the lake water surface equaled or exceeded fifty percent of the time during the Current period, was 98.0 ft above NGVD29. The Current P90 elevation, the elevation the lake water surface equaled or exceeded 90 percent of the time during the Current period, was 96.7 feet above NGVD29.

Water level data collected prior to January 1966 for Lake Hancock were classified as Historic data based on the assumption that replacement of the previously existing water control structure at the lake outlet with the P-11 structure that was constructed in August 1963 did not substantially affect lake water levels. However, the relatively short period of available Historic water level data for Lake Hancock limited the usefulness of these data for characterizing Historic water level fluctuations within the basin.

Historic lake-stage exceedance percentiles were therefore developed using a regression modeling approach was used for estimation of lake water levels that would be expected in the absence of potential withdrawal-related effects (see Appendix A). This approach was also considered appropriate for extending the period of record for lake stage values for developing Historic lake stage exceedance percentiles that could be used for development of proposed minimum and guidance levels. Development of an extended long-term stage record was considered necessary for characterization of the range of lake-stage fluctuations that could be expected based on long-term climatic cycles that have been shown to be associated with changes in regional hydrology (Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004).

The regression modeling for lake stage predictions was conducted using a linear fitting procedure known as the line of organic correlation (LOC) (see Helsel and Hirsch 1992 and Appendix A). The procedure was used to describe the relationship between daily water surface elevations for Lake Hancock derived from measured Historic data and various regional rainfall estimates determined from long-term rainfall stations in the lake vicinity.

Lake stage data used for development of LOC models for Lake Hancock consisted of daily lake surface elevations recorded from December 1958 through December 1965. Rainfall used for model development included cumulative totals, in inches, based on records from several area rainfall stations within the drainage basins contributing flow into the lake. The primary rain data used for development of a best-fit LOC model were collected at the National Weather Service's Lakeland (Linder Regional Airport, SID 18843) gauge located in the Saddle Creek basin. The period of record for this gauge is April 30, 1915 through December 31, 2001, with some infilled records for days with missing records (Aly 2008). Data collected after December 31, 2012 at the Lakeland 2 National Weather Service (NWS) gauge (SID 18048) also used for model development, with some infilling for this later period based on records from the Lakeland Public Works (SID 25176) gage. Cumulative rainfall totals were derived using a linear-decay series to weight monthly rainfall values for six-month and one through ten year periods. Final model selection was based on evaluation of the coefficient of determination (r^2) associated with models developed using each of the cumulative rainfall data sets.

The best-fit LOC model for predicting water levels in Lake Hancock exhibited a coefficient of determination (r^2) of 0.53. The model and rainfall records from area rainfall gages were used to estimate water levels for Lake Hancock for the 68-year period from January 1, 1946 through December 2014. Model-predicted water levels matched actual, i.e., observed period of record data reasonably well (Figure 26), indicating that the lake water levels fluctuate mostly in response to rainfall and impacts from groundwater withdrawals are minimal for most of the record. Because model predicted water levels closely matched observed data throughout the period of record, Long-term, historic percentiles (refer to Table 4) were developed using a composite of observed data and modeled data that was used to infill data gaps.

Based on the 68-year Historic water level record, the Historic P10 elevation, i.e., the elevation the lake water surface equaled or exceeded ten percent of the time, was 98.8 feet above NGVD29. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 97.6 feet above NGVD. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 96.7 feet above NGVD29.

The Historic lake stage exceedance percentile elevations are similar to percentiles derived from measured water levels for the lake. The Historic P10 and Historic P50 are, respectively, 0.1 higher and 0.4 feet lower than the P50 and P90 values for the measured records observed through 2014. The Historic P90 is the same as the P90 of the measured period of record water levels.

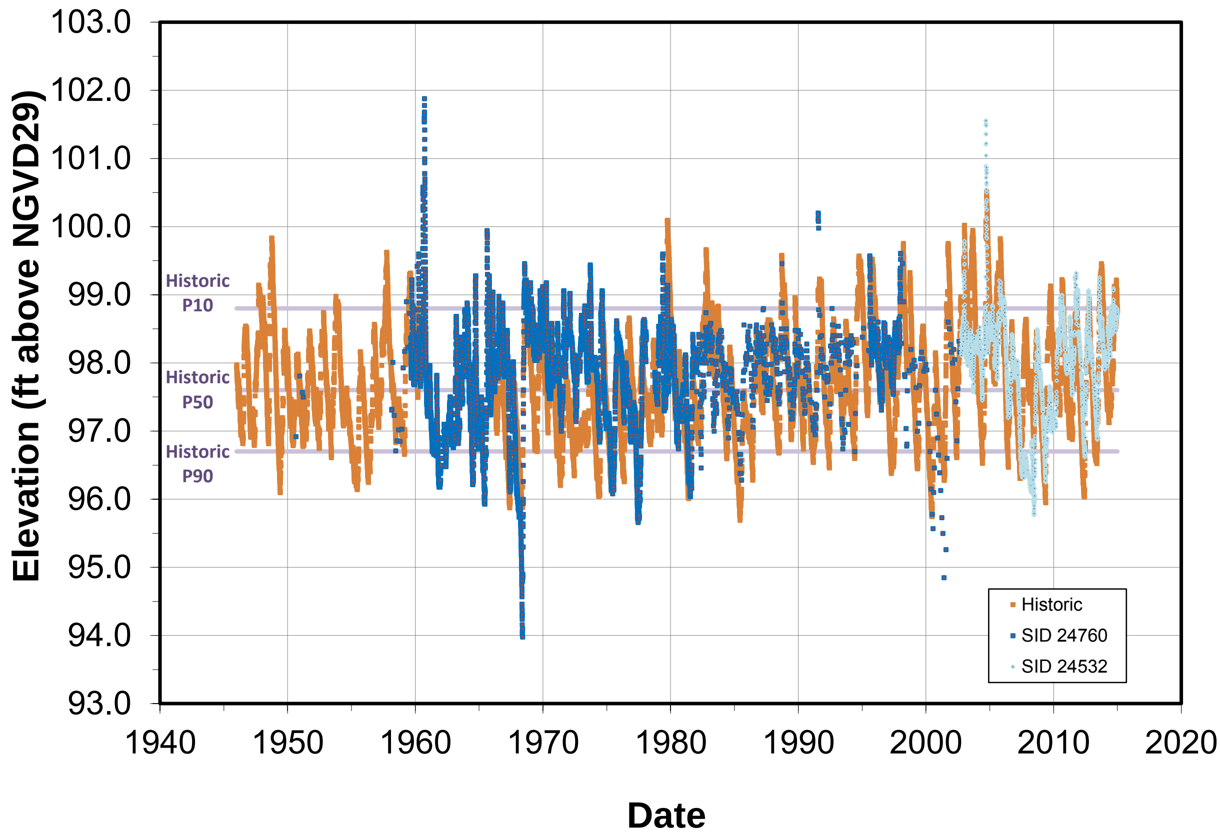


Figure 26. Observed water surface elevations and composite, Historic stage records and Historic percentiles for Lake Hancock for the period from August 1950 through 2014. Historic percentiles include water levels equaled or exceeded ten (Historic P10), fifty (Historic P50) and ninety (Historic P90) percent of the time.

Normal Pool, Control Point Elevation and Determination of Structural Alteration Status

The Normal Pool elevation, a reference elevation used for development of minimum lake and wetland levels, is established using elevations of Hydrologic Indicators of sustained inundation, including biological and physical features. For development of minimum lake levels, the Normal pool elevation is considered an approximation of the Long-term P10, which could be considered Historic if the Hydrologic Indicators used for establishing the Normal Pool developed in response to Historic hydrologic conditions.

Based on elevations of *Taxodium* sp. buttress inflection points measured in July 2004 along the west and north shores of the lake (see Figure 16), a Normal Pool elevation was established at 99.6 feet above NGVD (Figure 27, Table 4). Higher buttress inflection points were observed on larger and presumably older cypress along the lakeshore; two trees yielded inflection points at approximate elevations of 100.8 and 102.0 feet above NGVD (unpublished District data).

Previous investigations of the Lake Hancock shoreline have also documented a range of elevations associated with high-water line features. Patton and Associates, Inc. (1980) evaluated land-forms, vegetation and soils in the lake area and concluded that the Ordinary High Water Line associated with conditions prior to the onset of mining within the immediate lake basin was likely to have occurred at 100.5 feet above NGVD. They also observed terraces within the basin indicative of the landward extent of lake-water effects at higher elevations, in the range of 102.5 to 103.3 feet above NGVD. The Florida Department of Environmental Protection has identified a safe upland line for Lake Hancock at an elevation of 98.5 feet above NGVD (Malloy 2005).

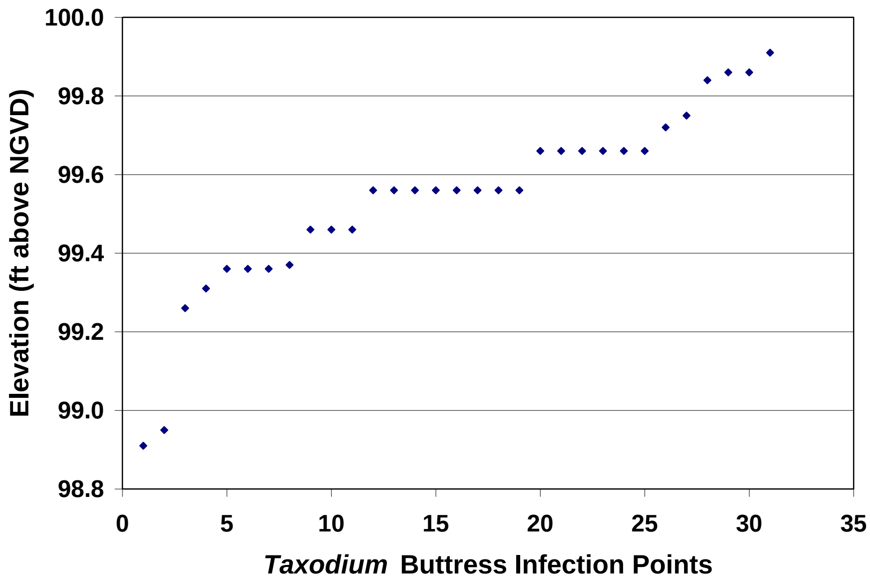


Figure 27. Elevations of cypress (*Taxodium sp.)* buttress inflection points used to establish the Normal Pool elevation for Lake Hancock.

Table 4. Summary statistics for hydrologic indicator measurements (elevations of the buttress inflection points of lakeshore *Taxodium* sp.) used for establishing the Normal Pool Elevation for Lake Hancock. Elevations were measured by District staff in July 2004.

Summary Statistic	Number (N) or Elevation (feet above NGVD29)
N	31
Median	99.6
Mean [Standard Deviation]	99.5 (0.23)
Minimum	98.9
Maximum	99.9

The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that principally controls lake water level fluctuations. A Control Point may be established at the invert or crest elevation associated with a water control structure at a lake outlet, or at a high, stable point in a lake-outlet canal, ditch or wetland area. The invert or crest elevations are the lowest point on the portion of a water-control structure that provides for conveyance of water across or through the structure. For non-operable structures, the crest elevation corresponds to the invert elevation. For operable structures, the invert elevation represents the lowest elevation at which flow may occur past the structure, and the crest elevation corresponds to the highest elevation that must be exceeded for flow to occur. The Control Point associated with an operable structure may, therefore, range from the invert elevation to the crest elevation.

The District's P-11 water control structure (see also Figures 6 and 16) in Saddle Creek is used to regulate water levels in Lake Hancock and downstream flow from the lake. The current P-11 structure became operational in May 2013, replacing a concrete and steel structure of the same name that was in use since August 1963 (Hammet et al. 1981), and which was preceded by a concrete and timber-pile weir that was previously used to control water levels in the lake basin.

The P-11 structure consists of an earthen embankment, a concrete spillway and a three-bay concrete structure with steel sheet pile driven to hard lime rock. Based on the invert elevations of the bays (92.0, 92.0 and 96.0 feet above NGVD29) and crest elevations for gates with the bays (102.0, 102.0 and 106.0 feet above NGVD29) a control point elevation for Lake Hancock was established as a range in elevations from 92.0 to 102.0 feet above NGVD29.

In addition to identification of current and historic outlet conveyance system modifications, comparison of the Control point elevation with the Normal Pool elevation can be used to evaluate the structural alteration status of a lake. If the Control Point elevation is below the Normal Pool, the lake is usually considered to be a structurally altered system. If the Control Point elevation is above the Normal Pool or the lake has no outlet, then the lake may not considered to be structurally altered. Based on the existence of the P-11 water control structure and given that the Normal Pool elevation (99.6 feet above NGVD) is higher than the bottom range of the Control point elevation identified for Lake Hancock, the lake was classified as a structurally altered lake. This characterization was used to support development of guidance levels, minimum levels and the modeling of Historic lake stage records.

Proposed Guidance Levels

The High Guidance Level is provided as an advisory guideline for construction of lakeshore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake, and is established using historic data if it is available, or is estimated using the Current P10, the Control Point elevation and the Normal Pool elevation. Based on the availability of Historic data for Lake Hancock, the proposed High Guidance Level was established at the Historic P10 elevation, 98.8 feet above NGVD.

The Low Guidance Level is provided as an advisory guideline for water dependent structures, and as information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis. The level is established using Historic or Current lake stage data and, in some cases, reference lake water regime statistics. Reference lake water regime statistics are used when adequate historic or current data are not available. These statistics represent differences between P10, P50 and P90 lake stage elevations for typical, regional lakes that exhibit little or no impacts associated with water withdrawals, i.e., reference lakes. Reference lake water regime statistics include the RLWR50, RLWR90 and RLWR5090, which are, respectively, median differences between P10 and P50, P50 and P90, and P10 and P90 lake stage percentiles for a set of reference lakes. Based on the availability of Historic data for Lake Hancock, the proposed Low Guidance Level was established at the Historic P90 elevation, 96.7 feet above NGVD.

The proposed guidance levels described in this document were not adopted into rule because they were based on water level conditions associated with conditions that existed prior to the recent modification of the District P-11 water control structure at the lake outlet. Current and future water levels conditions are expected to differ from previous conditions based on operation of the P-11 structure for storage of water in the lake and release of the stored water to support recovery of minimum flows in the Peace River.

Lake Classification

Lakes are classified as Category 1, 2 or 3 for minimum levels development. Systems with fringing cypress wetlands greater than 0.5 acres in size where water levels regularly rise to an elevation expected to fully maintain the integrity of the wetlands, i.e., the Historic P50 is not more than 1.8 feet below the Normal Pool elevation, are classified as Category 1 Lakes. Lakes with fringing cypress wetlands greater than 0.5 acres in size that have been structurally altered such that the Historic P50 is more than 1.8 feet below the Normal Pool elevation are classified as Category 2 Lakes. Lakes without fringing cypress wetlands or with less than 0.5 acres of fringing cypress wetlands are classified as Category 3 Lakes. Based on the occurrence of lake-fringing cypress wetlands of 0.5 acre or more in size within the lake basin, and because the Historic P50 is more than 1.8 feet below the Normal Pool elevation, Lake Hancock was classified as a Category 2 lake.

Significant Change Standards and Other Information for Consideration

Lake-specific significant change standards and other available information are developed for establishing minimum levels. The standards are used to identify thresholds for preventing significant harm to environmental values associated with lake ecosystems (see Table 1), in accordance with guidance provided in the Florida Water Resource Implementation Rule (Rule 62-40.473, F.A.C.). Other information taken into consideration for minimum levels development includes potential changes in the coverage of herbaceous wetland and submersed aquatic plants.

For Category 1 or 2 Lakes, a significant change standard is established 1.8 feet below the Normal Pool elevation. This standard identifies a desired median lake stage that if achieved, may be expected to preserve the ecological integrity of lake-fringing wetlands. Although not identified by name in the District's Minimum Flows and Levels rule, the elevation 1.8 feet below normal pool is typically referred to as the Cypress Standard in District documents pertaining to minimum levels development. For Lake Hancock, the Cypress Standard was established at 97.8 feet above NGVD. Based on the Historic, composite water level record, the standard was equaled or exceeded forty-one percent of the time, i.e., the standard elevation corresponds to the Historic P41.

For Category 3 lakes, six significant change standards, including a Basin Connectivity Standard, a Recreation/Ski Standard, an Aesthetics Standard, a Species Richness Standard, a Lake Mixing Standard and a Dock-Use Standard are typically developed. These standards identify desired median lake stages that if achieved, are intended to preserve various natural system and human-use environmental values. Although Lake Hancock is a Category 2 Lake, Category 3 Lake standards were developed for comparative purposes. These standards were not, however, used to establish the minimum levels.

The Basin Connectivity Standard is developed to protect surface water connections between lake basins or among sub-basins within lake basins to allow for movement of aquatic biota, such as fish, and support recreational use of the lake. The standard is based on the elevation of lake sediments at a critical high spot between lake basins or lake sub-basins, identification of water depths sufficient for movement of biota and/or watercraft across the critical high spot, and use of Historic lake stage data or region-specific Reference Lake Water Regime statistics. A Basin Connectivity Standard was established for Lake Hancock at 97.4 feet above NGVD, based on the 94.5 feet above NGVD elevation that ensures connectivity between the main lake sub-basins, a two-foot water depth in the areas of connectivity to allow for movement of watercraft and biota between the sub-basins, and the 0.9-foot difference between the Historic P50 and Historic P90 elevations. Based on the Historic, composite water level record, the standard was equaled or exceeded sixty percent of the time, *i.e.*, the standard elevation corresponds to the Historic P60.

The Recreation/Ski Standard is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation (the Ski Elevation) within the basin that can contain a 5-foot deep ski corridor delineated as a circular area with a radius of 418 feet, or a rectangular ski corridor 200 feet in width and 2,000 feet in length, and use of Historic lake stage data or region-specific reference lake water regime statistics. For Lake Hancock, a Recreation-Ski Standard was established at 97.4 feet above NGVD, based on the sum of the 96.5 ft above NGVD Ski Elevation and the 0.9-foot difference between the Historic P50 and Historic P90. Based on the Historic, composite water level record, the standard was equaled or exceeded sixty percent of the time, i.e., the standard elevation corresponds to the Historic P60.

The Aesthetics Standard is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from diminishing beyond the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard is established at the Low Guidance Level, which for Lake Hancock occurs at an elevation of 96.7 feet above NGVD. Because the Low Guidance Level was established at the Historic P90 elevation, water levels equaled or exceeded the standard ninety percent of the time during the Historic period, based on the Historic, composite water level record

The Species Richness Standard is developed to prevent a decline in the number of bird species that may be expected to occur at or utilize a lake. Based on an empirical relationship between lake surface area and the number of birds expected to occur at a lake, the standard is established at the lowest elevation associated with less than a fifteen percent reduction in lake surface area relative to the lake area at the Historic P50 elevation. For Lake Hancock, a Species Richness Standard was established at 95.3 feet above NGVD. The standard was equaled or exceeded one hundred percent of the time, based on the Historic, composite water level record. The Species Richness Standard therefore corresponds to the Historic P100.

The Lake Mixing Standard is developed to prevent significant changes in patterns of wind-driven mixing of the lake water column and sediment re-suspension. The standard is established at the highest elevation at or below the Historic P50 elevation where the dynamic ratio (see Bachmann et al. 2000) shifts from a value of <0.8 to a value >0.8, or from a value >0.8 to a value of <0.8. For Lake Hancock, this occurs at a lake surface elevation on 90.6 feet above NGVD (refer to Figure 25). Based on the Historic, composite water level record, this elevation was exceeded one hundred percent of the time. Given that the lake area associated with a water surface elevation equivalent to the standard elevation would be approximately one acre, use of the standard would not be appropriate for minimum levels development.

The Dock-Use Standard is developed to provide for sufficient water depth at the end of existing docks to permit mooring of boats and prevent adverse impacts to bottom-dwelling plants and animals caused by boat operation. The standard is based on the elevation of lake sediments at the end of existing docks, a two-foot water depth for boat mooring, and use of Historic lake stage data or region-specific reference lake water regime statistics. Because only a few docks occur within the lake basin, a Dock-Use Standard was not developed for Lake Hancock.

Herbaceous Wetland Information is taken into consideration to determine the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (i.e., basin area with a water depth of four or less feet). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values. Review of changes in potential herbaceous wetland area or area available for aquatic plant colonization in relation to change in lake stage did not indicate that of use of any of the significant change standards, with the exception of the Lake Mixing Standard, would be inappropriate for establishment of minimum levels (Figure 28).

Because herbaceous wetlands are common within the Lake Hancock basin, it was determined that an additional measure of wetland change should be considered for minimum levels development. Based on a review of the development of minimum level methods for cypress-dominated wetlands (Hancock 2006), it was determined that up to an 0.8-foot decrease in the Historic P50 elevation would not likely be associated with significant changes in the herbaceous wetlands occurring within west-central Florida lake basins. A Wetland Offset elevation of 96.8 feet above NGVD was therefore established for Lake Hancock by subtracting 0.8 feet from the Historic P50 elevation. The standard elevation was equaled or exceeded eighty-seven percent of the time, based on the Historic, composite water level record. The Wetland Offset Elevation therefore corresponds to the Historic P87.

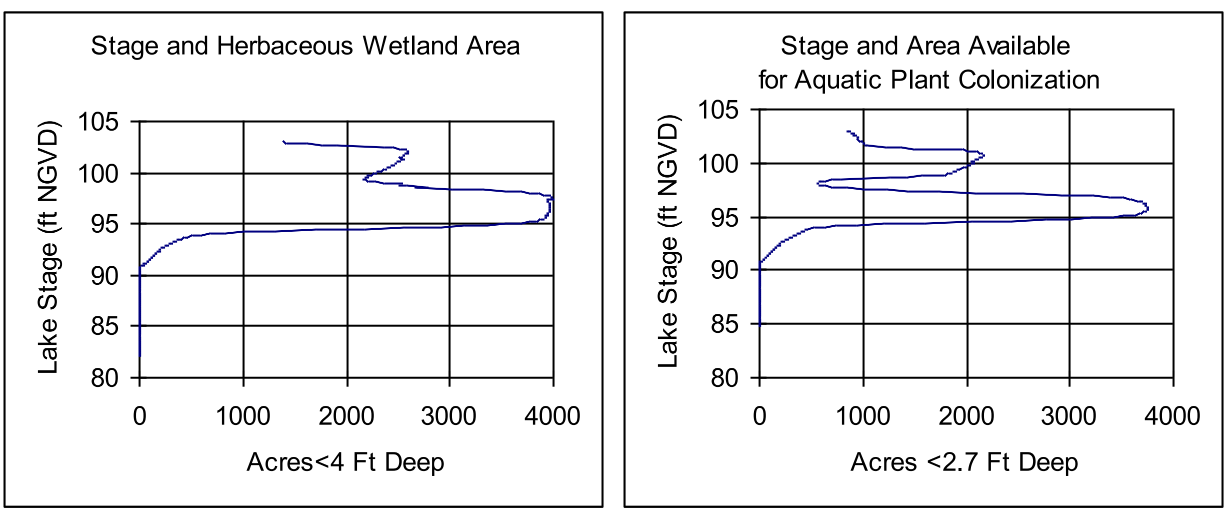


Figure 28. Potential herbaceous wetland area and area available for macrophyte colonization in Lake Hancock as a function of lake stage.

Minimum Levels

Minimum lake levels are developed using specific lake-category significant change standards and other available information or unique factors, including: potential changes in the coverage of herbaceous wetland vegetation and aquatic macrophytes; elevations associated with residential dwellings, roads or other structures; frequent submergence of dock platforms; faunal surveys; aerial photographs; typical uses of lakes (e.g., recreation, aesthetics, navigation, irrigation); surrounding land-uses; socio-economic effects; and public health, safety and welfare matters. Minimum levels development is also contingent upon lake classification, i.e., whether a lake is classified as a Category 1, 2 or 3 lake.

The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. For Category 2 lakes, the Minimum Lake Level is established at the Historic P50 elevation. A Minimum Lake Level for Lake Hancock was therefore established at 97.6 feet above NGVD.

The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For Category 2 lakes, the High Minimum Lake Level is established at the High Guidance Level. A High Minimum Lake Level for Lake Hancock was therefore established at 98.8 feet above NGVD.

Minimum and proposed guidance levels for Lake Hancock are listed in Table 5 and shown in Figure 29 along with observed period of record daily water surface elevations. The approximate locations of the lake margin when water levels equal the minimum levels are shown in Figure 30.

Because many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, U.S. Geological Survey, and the District are in the process of migrating from NGVD29 to the NAVD88 vertical control standard, the minimum and proposed guidance levels for Lake Hancock relative to NAVD88 are included in Table 5. The NAVD88 elevations were estimated using a datum conversion of 0.88 feet derived with Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

Table 5. Minimum and proposed Guidance Levels for Lake Hancock relative to the National Geodetic Vertical Datum of 1929 (NGVD29) and the North American Vertical Datum of 1988 (NAVD88).

Minimum and Proposed Guidance Levels	Elevation (feet above NGVD29)	Elevation (feet above NAVD88)
High Guidance Level [a]	98.8 [a]	97.9
High Minimum Lake Level	98.8	97.9
Minimum Lake Level	97.6	96.7
Low Guidance Level [a]	96.7 [a]	95.8

[a] Proposed guidance levels were not adopted into District rules.

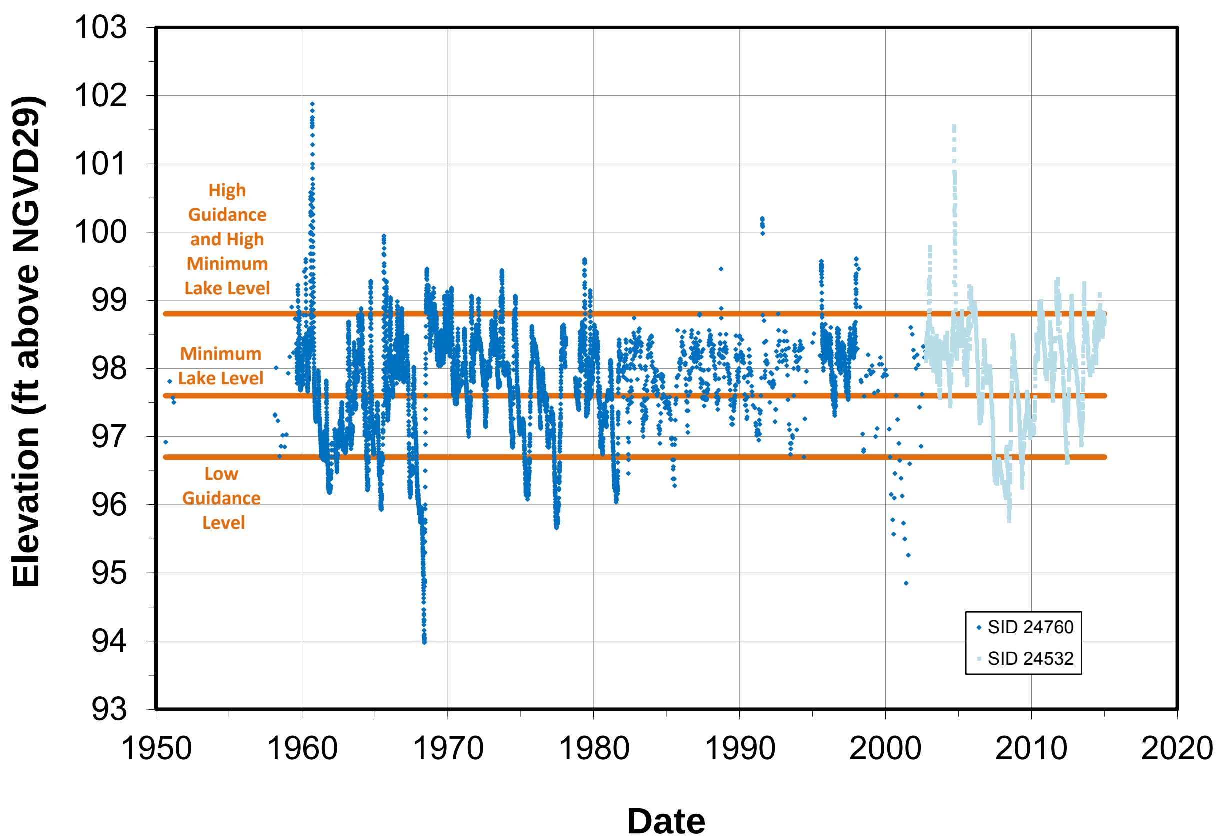


Figure 29. Minimum and proposed guidance levels (horizontal lines) and observed water surface elevations (points) at two gage sites (SID 24760 and 24532) in Lake Hancock through December 31, 2014.

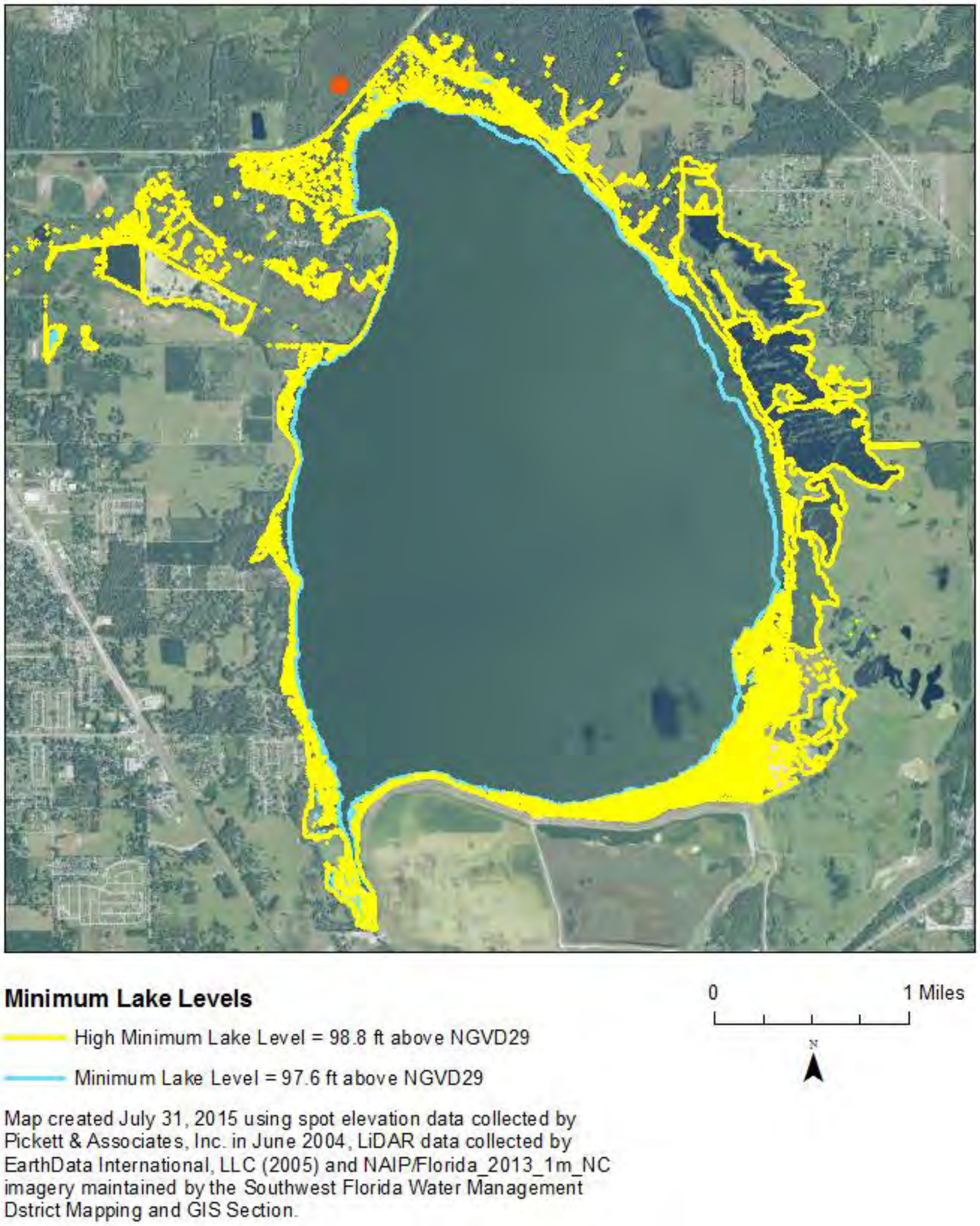


Figure 30. Approximate location of elevation contours associated with minimum levels for Lake Hancock. The orange dot indicates an area where elevation contours were truncated for mapping purposes.

Consideration of Environmental Values

The minimum levels for Lake Hancock are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.). When developing minimum lake levels, the District evaluates categorical significant change standards and other available information to identify criteria that are sensitive to long-term changes in hydrology and represent significant harm thresholds.

A Cypress Standard was identified to support development of minimum levels for Lake Hancock based on the occurrence of lake-fringing cypress wetlands of one-half an acre or greater in size. The standard is associated with protection of several environmental values identified in the Water Resource Implementation Rule, including: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (refer to Table 1). Ultimately, the Historic P50 elevation and High Guidance Level/Historic P10 were used for developing minimum levels for Lake Hancock, based on existing structural alterations and its classification as a Category 2 Lake. Given that the minimum levels were established using Historic lake stage exceedance percentiles, the levels are as protective of all relevant environmental values as they can be, given the existing structural alterations. In addition, the environmental value, maintenance of freshwater storage and supply is also expected to be protected by the minimum levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in the Water Resource Implementation Rule, were not considered relevant to development of minimum levels for Lake Hancock. Estuarine resources were not considered relevant because the lake is only remotely connected to the estuarine resources associated with the downstream receiving waters of Charlotte Harbor, and water level fluctuations in the lake are expected to exert little effect on the ecological structure and functions of the bay. Sediment loads were similarly not considered relevant for minimum levels development for the lake, because the transport of sediments as bedload or suspended load is a phenomenon typically associated with flowing water systems.

Minimum Levels Status Assessment

The goal of a minimum levels status assessment is to determine if lake levels are fluctuating in accordance with criteria associated with adopted or proposed levels, i.e., to determine whether the minimum levels are being met. In addition to use of a rainfall regression model and/or other types of models, the process includes comparison of long-term water levels with adopted or proposed levels, review of periodic groundwater modeling updates, and, if necessary, investigation of other factors that could help explain lake level fluctuations.

To assess whether the Minimum Lake Level adopted for Lake Hancock is being met, observed water levels were compared to levels predicted using the best-fit LOC model that was developed for predicting long-term historic water levels in the lake. Comparison of the observed data with modeled results allows for assessment of impacts from groundwater withdrawals. From January 2000 through 2014, water levels predicted with the LOC model and the observed water levels are similar (see Figure 25 in Appendix A). There were two extended periods, one in 2006 and one in 2008, when observed levels were lower than the predicted values. Factors accounting for these differences are not known, but could be associated with model or data deficiencies or related to structure operations. Other than during the periods in 2006 and 2008, model predicted and observed water levels exhibit good agreement, especially considering the P-11 structure at the lake outlet was operated to manage lake levels and flow to the Peace River.

The use of the prediction intervals generated from the LOC model calibration period residuals as described in Appendix A provided another approach for evaluating the status of Lake Hancock with regard to the adopted Minimum Lake Level. For this assessment, annual average water levels from 2008 through 2014 were plotted with along with water levels predicted with the LOC model and 95% prediction intervals for the model (Figure 31). All annual average water levels evaluated for Lake Hancock plotted above the lower prediction interval for the model, indicating the Minimum Lake Level is being met.

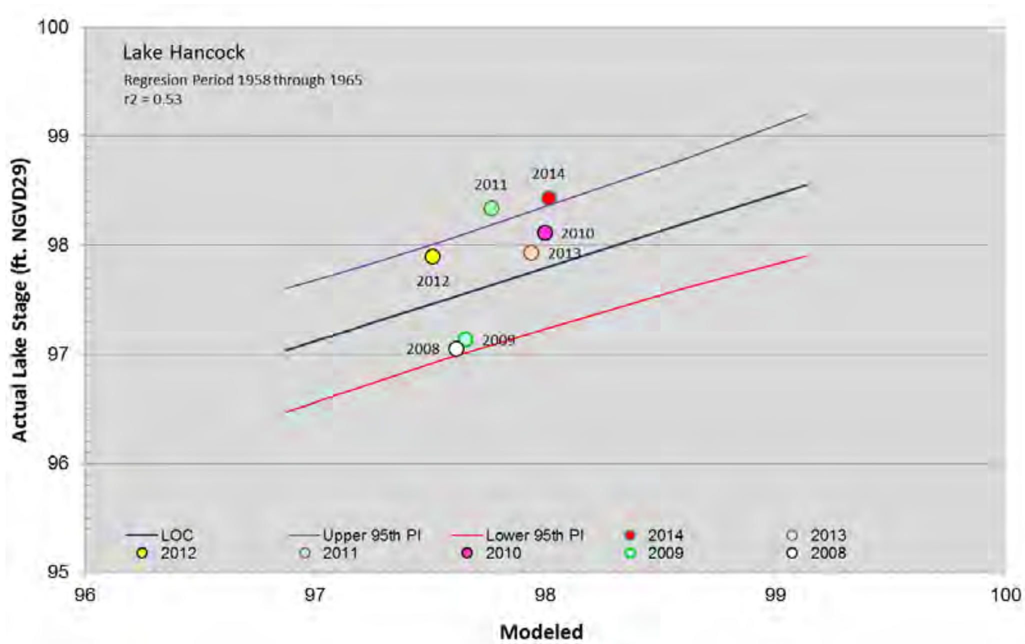


Figure 31. Modeled (LOC with upper and lower 95th prediction invervals) and annual average lake stage values for 2008 through 2014 (reproduced from Figure 27 in Appendix A).

Assessment of the status of the minimum levels adopted for Lake Hancock using the observed stage record from 1959 through the present allowed for evaluation of the lake levels relative to the history of withdrawals in the area, which has been variable through time. Cumulative median (P50) and cumulative P10 water surface elevations were calculated for this period and for a shorter period starting in 2002, and these cumulative values were the sets of hydrologic statistics were compared with the proposed Minimum Lake Level and High Minimum Lake Level. Cumulative medians for both evaluated start dates ended with values above the Minimum Lake Level (Figure 32). The cumulative P10s for the two periods ended up approximately 0.1 feet below the High Minimum

Lake Level (Figure 32) and this is likely due to historical structure operations intended to maintain a maximum desirable water surface elevation of 98.7 feet above NGVD29. Adjustments that could have been made to historical structure operations would be expected to have led to achieving the High Minimum Lake Level, so the ~0.1 ft difference between the evaluated cumulative P10 values and the High Minimum Lake Level was not considered sufficient to suggest the level was not and could not have been met.

Because the minimum levels in Lake Hancock are considered to currently be met, and the P-11 structure at the lake outlet was recently modified to increase storage in the lake basin for release to the Peace River to recover minimum flows, the High Minimum and Minimum Lake Level for Lake Hancock are also expected to be met for the next 20-year planning period.

The District plans to continue regular monitoring of water levels in Lake Hancock and will also routinely evaluate the status of the lake's water levels with respect to the adopted minimum levels for the lake that are included in Chapter 40D-8, F.A.C. If the event that the need for recovery of minimum levels in the lake is identified, the SWUCA recovery strategy (Rule 40D-80.074, F.A.C. and SWFWMD 2006) would be applicable.

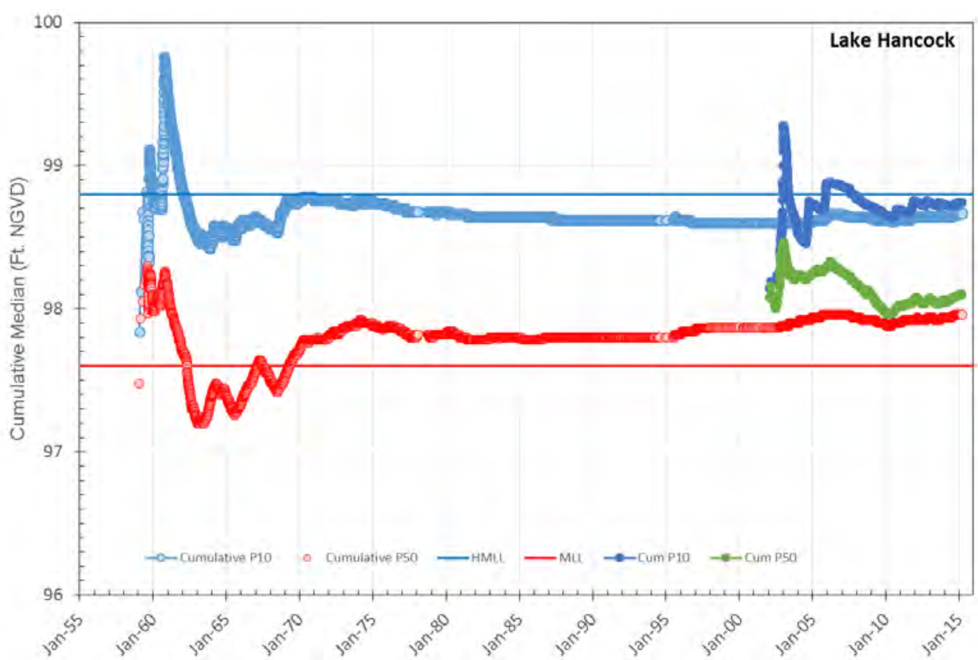


Figure 32. Cumulative median and P10 water level for Lake Hancock starting in 1959 and 2002 (reproduced from Figure 28 in Appendix A).

Lake Hancock Lake Level Modification and Outfall Structure P-11 Modification Projects

The District is currently implementing major water-resource projects that will affect water levels in Lake Hancock. These projects are part of the strategy outlined in the SWUCA Recovery Plan for meeting minimum flow requirements that are not being met for the upper segment of the Peace River. The projects include increasing the previously used typical operating level for the lake from 98.7 feet above NGVD29 to 100.0 feet above NGVD29 through operation of the recently modified P-11 structure at the lake outfall. The modifications to the structure and changes in the structure operation schedule will allow the District to increase storage of water in the lake basin for release through Saddle Creek to the Peace River.

With support from a consultant, the District has developed a water budget model for evaluating the effects of the proposed projects on water levels in the Lake Hancock basin (BCI Engineers & Scientists, Inc. 2005a, 2006b). Predicted daily water surface elevations for the 36-year period from January 1975 through December 2010 based on the proposed structural and operational modifications were developed by Harry Downing of the District's Engineering Section using the water budget model. Model results are shown in Figure 33 along with daily water surface elevations based on measured and interpolated values derived from measured values. Comparison of the measured and modeled records shown in Figure 33 clearly illustrates how the proposed structural and operational changes may be expected to increase water surface elevations in Lake Hancock.

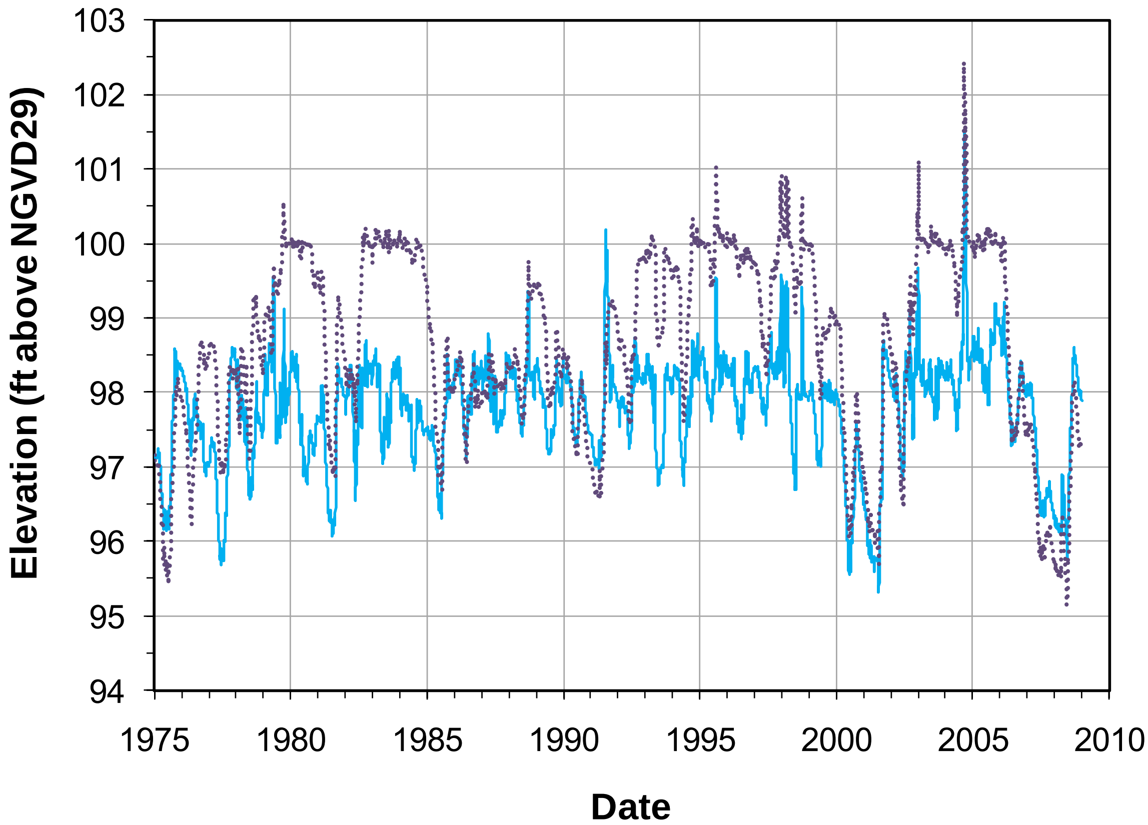


Figure 30. Measured (solid blue line) and modeled (dashed purple line) daily water surface elevations for Lake Hancock from January 1, 1975 through December 31, 2010. Measured elevations include some interpolated values. Modeled water surface elevations were based on operation of the recently constructed District P-11 water control structure to address recovery of minimum flows in the upper Peace River and elimination of inflows to the lake that were associated with historical discharges from the City of Lakeland Waste Water Treatment Plant.

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Appendix A

Ellison, D.L. 2015 [updated 2017]. Draft technical memorandum to Douglas A. Leeper, dated September 15, 2015 [updated April 7, 207]. Subject: Lake Hancock hydrogeology, rainfall regression models, historic percentile estimations, and assessment of minimum lake levels status. Southwest Florida Water Management District. Brooksville, Florida.

Technical Memorandum

DATE: September 15, 2015 [Updated May 24, 2017]

TO: Douglas A. Leeper, MFLs Program Lead, Natural Systems and Restoration Bureau

FROM: Donald L. Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau

SUBJECT: Lake Hancock Hydrogeology, Rainfall Regression Models, Historic Percentile Estimations, and Assessment of Minimum Lake Levels Status

A. Introduction

A rainfall regression model was developed to assist the Southwest Florida Water Management District (District or SWFWMD) in the establishment of minimum and guidance levels for Lake Hancock, located in southeast Polk County (Figure 1). This document discusses development of the model, hydrogeologic evaluations used to support model development, derivation of lake stage percentiles used to develop proposed levels for the lake, and minimum level status assessments. Status assessment evaluates whether long-term water levels in the lake are above currently and projected to stay above the proposed minimum levels, i.e., whether the levels are being met and may be expected to be met for the next twenty years.

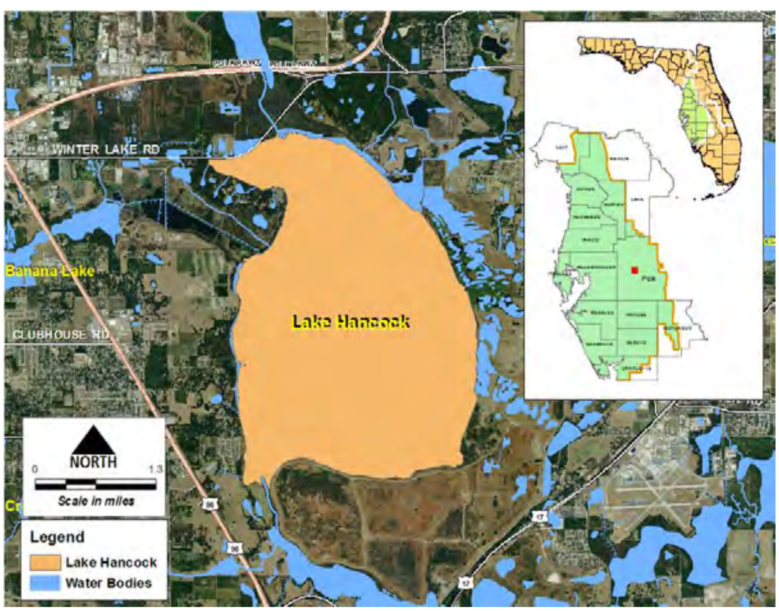

Figure 1. Location of Lake Hancock in Polk County, Florida.

B. Background and Setting

Lake Hancock is in west central Polk County, (Figure 1). The lake receives flow from the Saddle Creek, Banana Lake Outlet and Lake Lena Run basins which lie within the larger Peace River watershed (Figure 2). White (1970) classified the physiographic area as the Polk Upland bordered to the east by the Winter Haven Ridge and to the west by the Lakeland Ridge (Figure 3). The area surrounding the lake is categorized as the Bartow Embayment subdivision of the Central Lakes Physiographic District (Brooks, 1981 (Figure 4). The Bartow Embayment is described as a large erosional basin partially filled with the phosphatic sand and clayey sands of the Bone Valley Formation of Pliocene age. The topography is relatively flat, and drainage into the lake is a combination of flow from the Saddle Creek, Lake Lena Run, and Banana Lake Outlet with overland flow and other flow from drainage swales and minor flow systems.

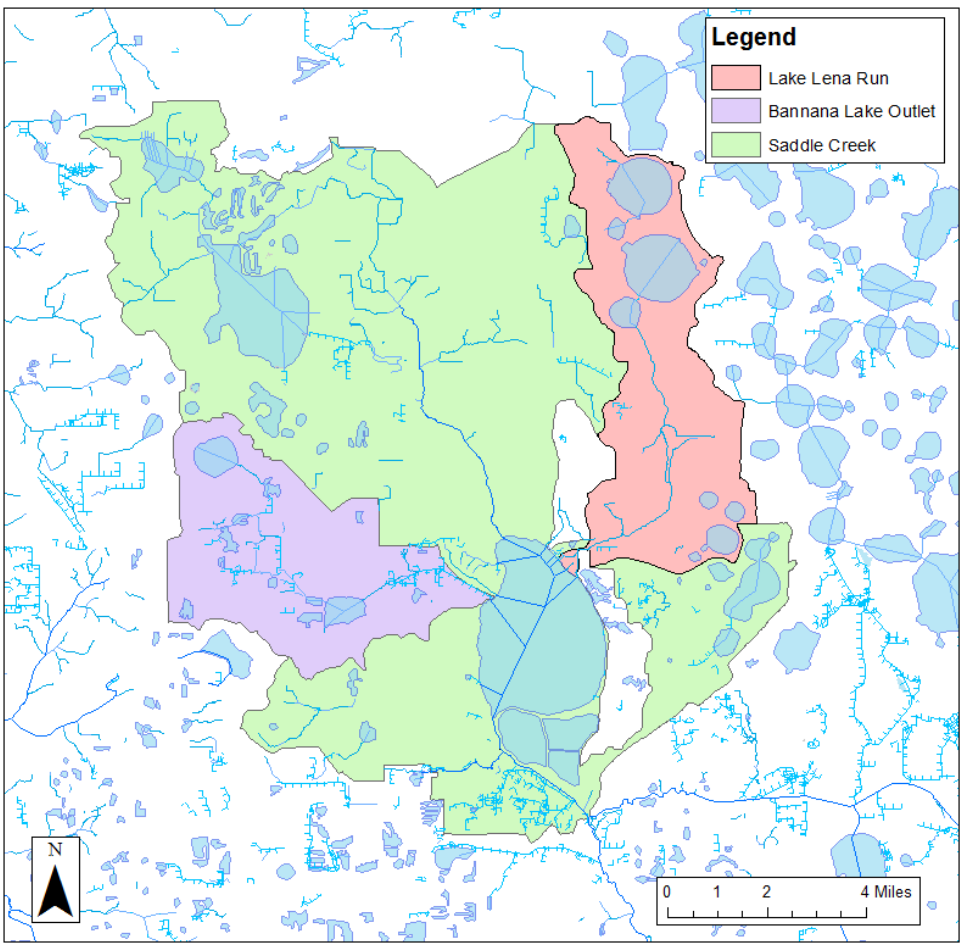

Figure 2. Drainage Basin delineation.

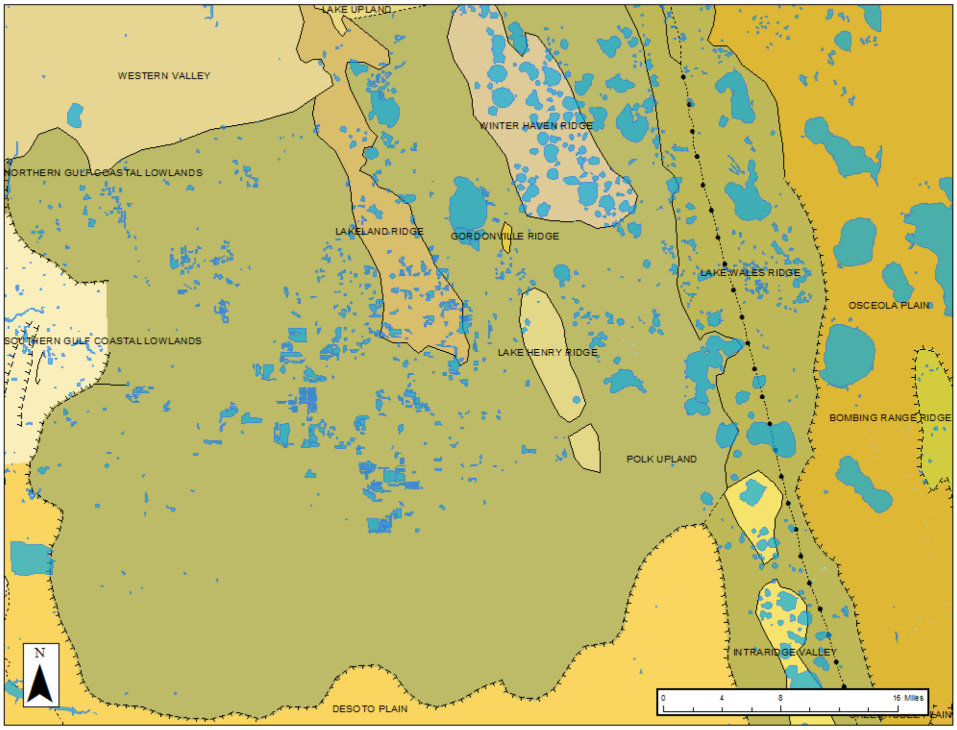

Figure 3. Physiographic provinces (White 1970).

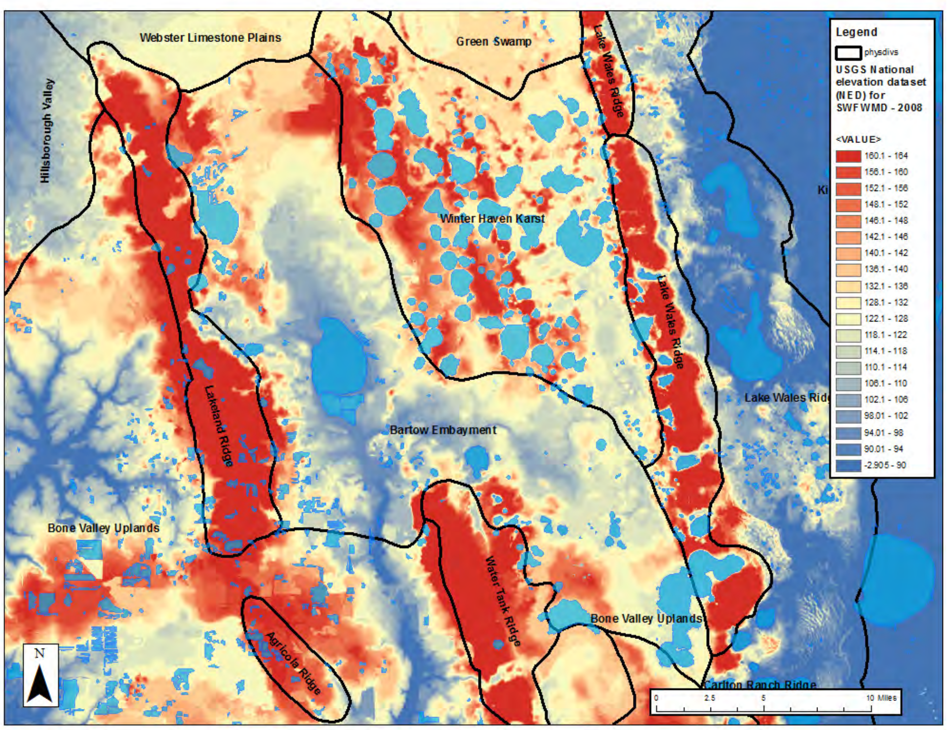

Figure 4. Physiographic Provinces (Brooks, 1981) and topography (USGS National elevation dataset for SWFWMD 2008).

In general the hydrogeology of the area starting at landsurface includes an unconsolidated surficial deposit of sand grading down to clay; a confined intermediate aquifer system (IAS) which consists of a series of thin, interbedded limestone and phosphatic clays of generally low permeability; and finally the thick carbonate Upper Floridan aquifer (UFA). The base of the surficial aquifer (SA) consists of Pliocene age clays and clayey sands that form the top of the IAS. The IAS in this area is composed of the Hawthorn group which varies in thickness from 90 to 200 feet and forms an effective confinning unit. The Hawthorn group in this area consits of the Bone Valley Member of the Peace River Formation, Peace River Formation, and the Arcadia Formation. Lithologic descriptions from borings around the lake report a high percentage of clayey sands and clay (Figures 5 and 6). Surface elevations of the Hawthorn Formation shows a surface that slopes to the east (Figure 7). Surface elevations of the Suwannee Limestone shows Lake Hancock is positioned over a high ridge that slopes away to the south and east (Figure 8). North-south and east-west cross sections show Lake Hancock is positioned in the low permeability Hawthorn Formation which attenuates and lessens the efects of drawdown from groundwater withdrawals in the Upper Floridan aquifer (Figures 9 and 10)

Figure 5. Location of Lithologic Log W-8879.

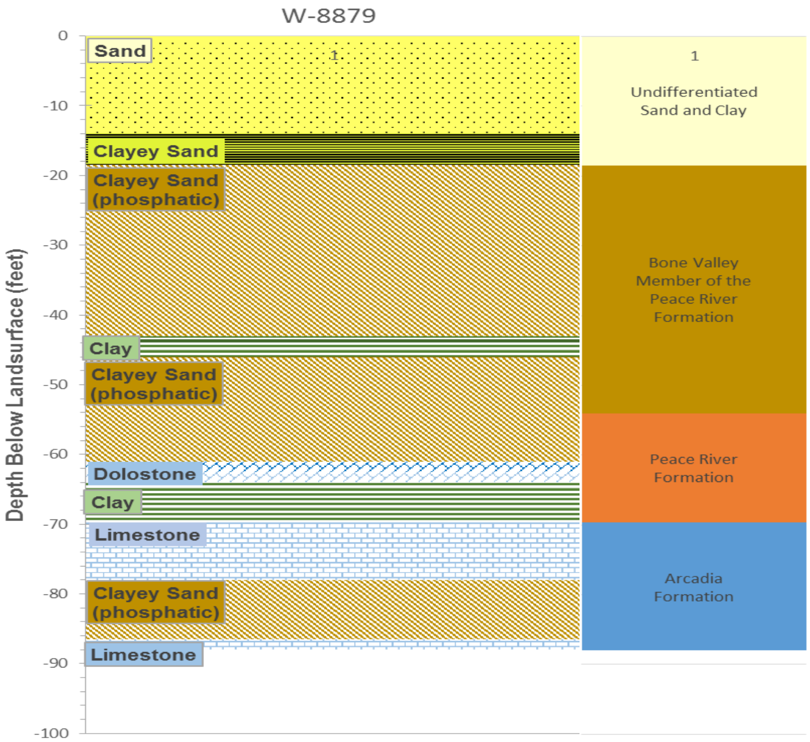

Figure 6. Lithologic description from W-8879.

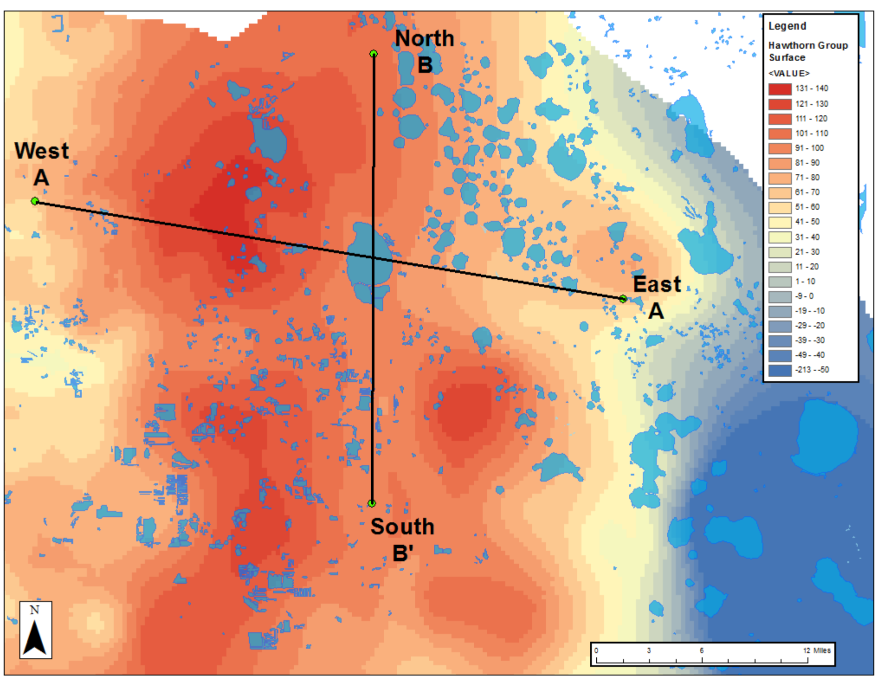

Figure 7. Surface elevations (feet NGVD29) or the top of the Hawthorn Formation and north-south and east-west geologic cross section alignments.

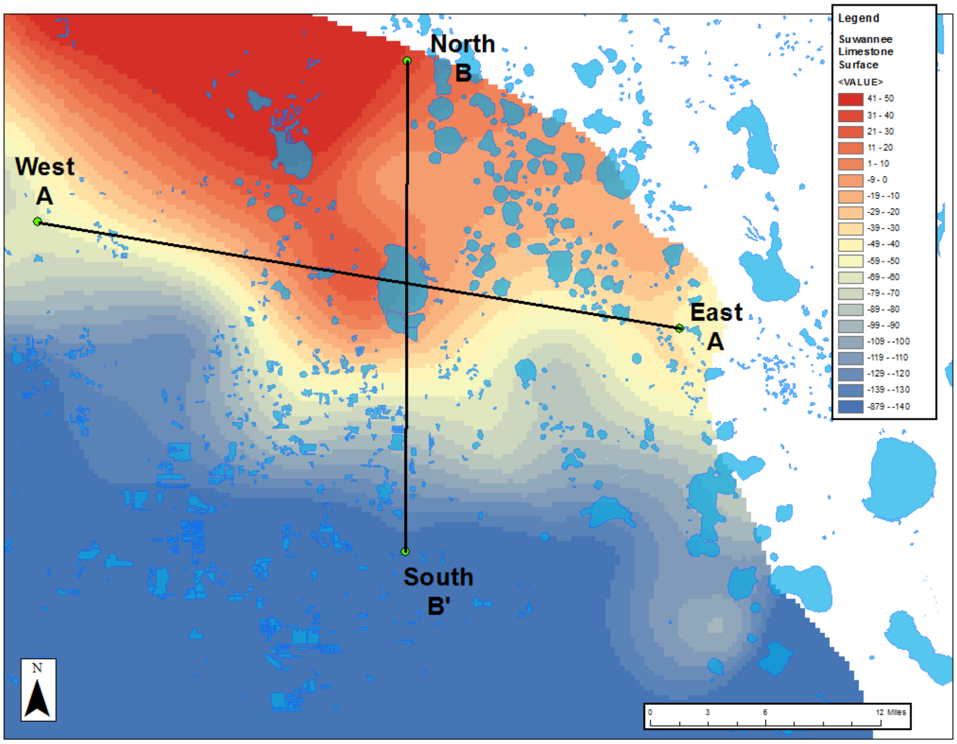

Figure 8. Surface elevations (feet NGVD29) or the top of the Suwannee Limestone and north-south and east-west geologic cross section alignments.

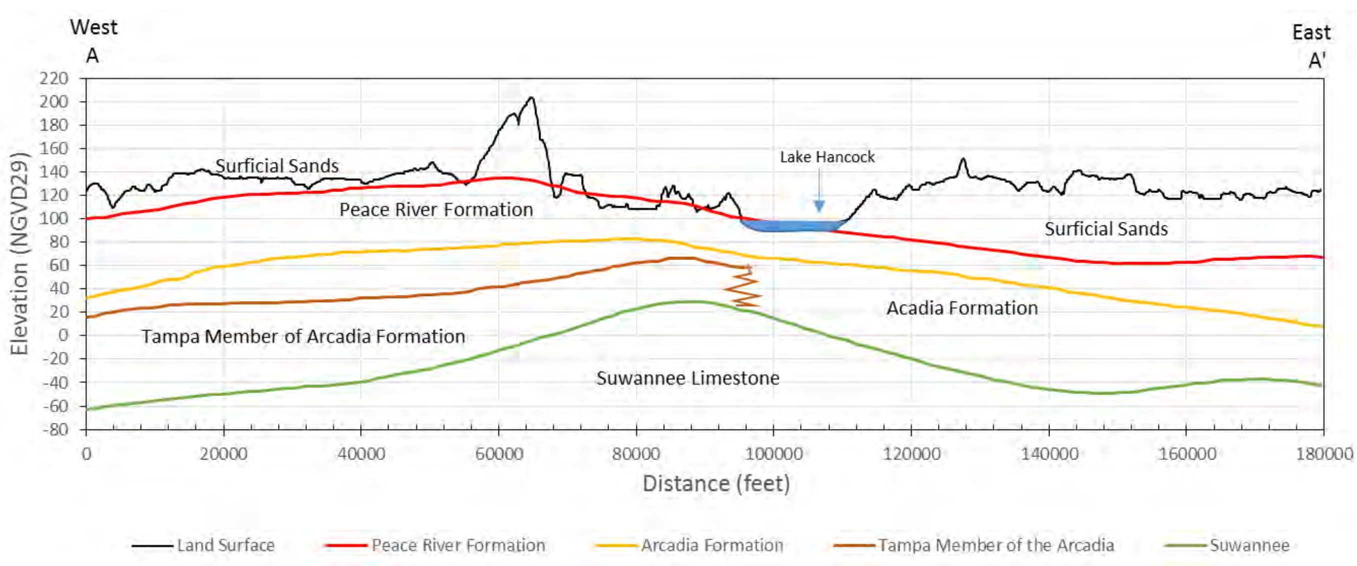

Figure 9. East-west geologic crossection (refer to figure 7 for alignment).

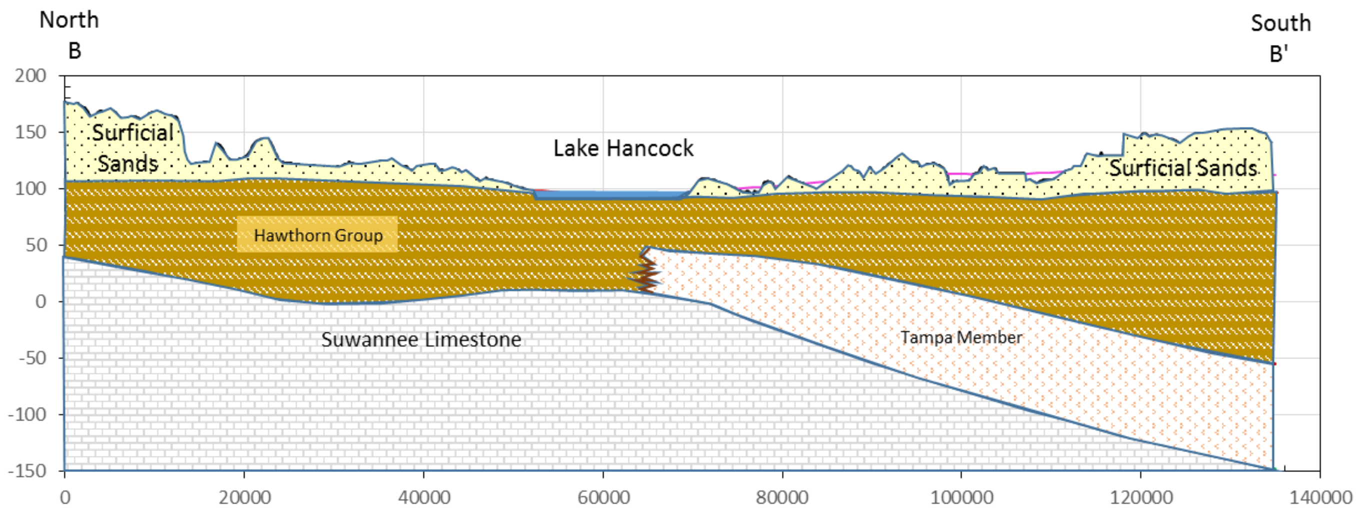

Figure 10. North-South geologic crossection (refer to figure 7 for alignment).

In general the surficial aquifer is not in good connection with the underlying UFA. Large head differences between the surficial and Upper Floridan monitoring wells ranging from 15 to 45 feet demonstrates the effectiveness of the confining unit between the SA and UFA (Figures 11, 12, 13). Sink holes have occurred within the main body of the lake resulting in rapid water level declines on the order of 2 feet. A good example of sink hole effects on the lake occurred in 1968 when at least one sink hole opened in the lake (Figure 17). Natural processes resulted in partial infilling and a subsequent recovery of the lake.

The UFA is a carbonate sequence comprised of the Suwannee Limestone, Ocala Limestone, and portions of the Avon Park Formation. It generally consists of two permeable zones and one semi-confining unit. The term “permeable zone” has been adopted from previous literature (Hickey, 1982) and describes an identifiable horizon of enhanced water producing capabilities. The top of the UFA generally coincides with the top of the Suwannee Limestone, which is the upper permeable zone (Basso, 2003). It is composed of a fossiliferous, biogenic calcarenite that contains moldic porosity. Below this zone, little apparent contribution of flow occurs due to the low permeability, fine-grained, chalky limestone of the Ocala Formation. The top of the Suwannee Limestone is sometimes marked by lost drilling circulation and is typically a zone of enhanced permeability.

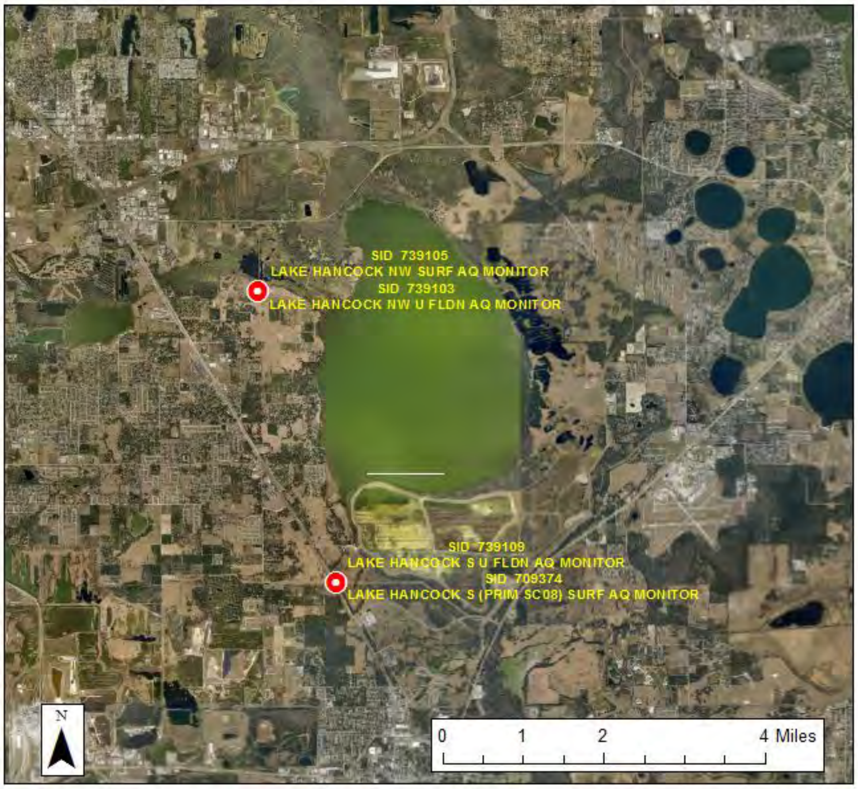

Figure 11. Location of paired Upper Floridan and Surficial aquifer wells.

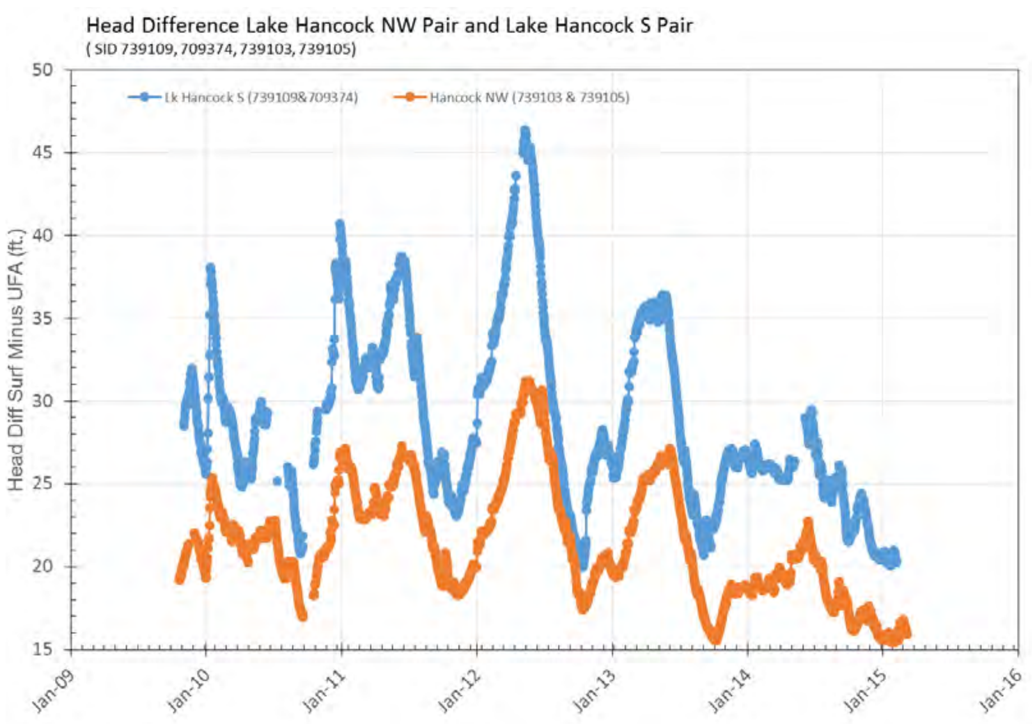

Figure 12. Head difference (Surficial minus Upper Floridan water levels) for Lake Hancock South (S) and Lake Hancock Northwest (NW) Surficial and Upper Floridan aquifer monitoring well pairs.

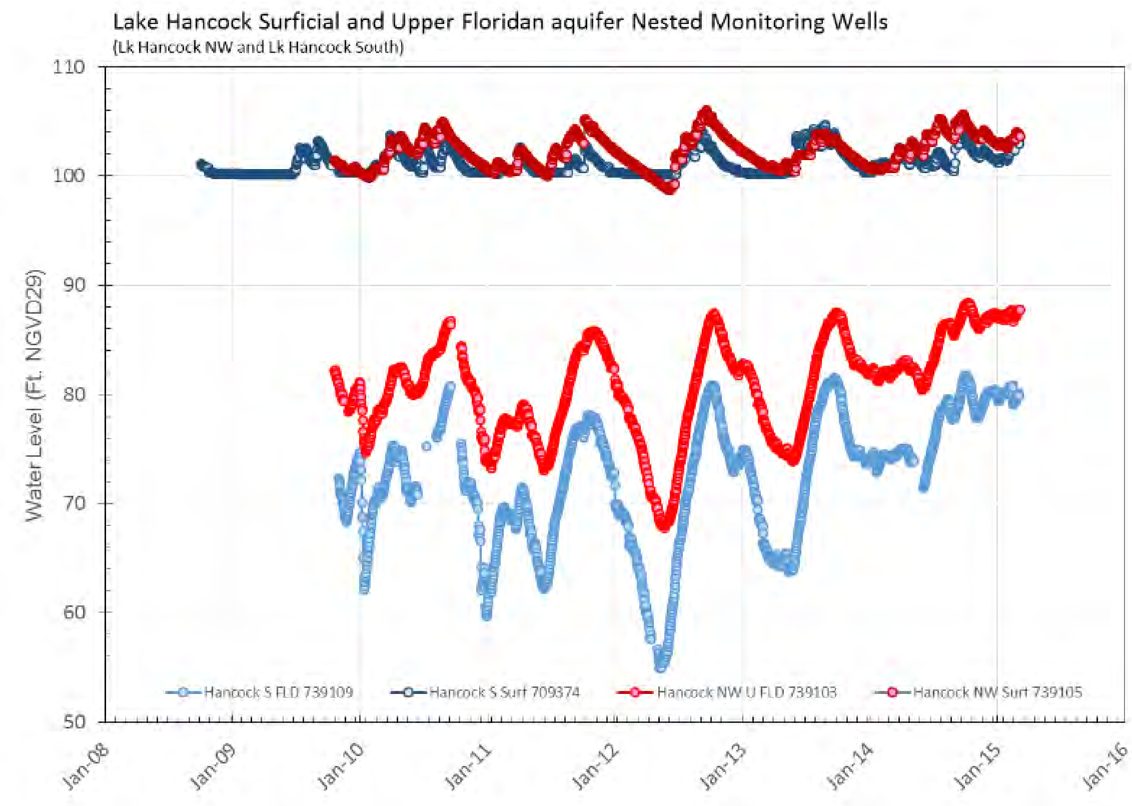

Figure 13. Hydrographs for Lake Hancock NW and Lake Hancock South monitoring well pairs.

Underlying the Suwannee Limestone is a semi-confining unit (SCU) that typically corresponds stratigraphically with the top of the Ocala Limestone. It is mostly composed of a soft, chalky, fine-grained, foraminiferal calcilutite and calcarenitic limestone. Near the lower portion, the Ocala Formation may contain sucrosic, dolomitic limestone. The semi-confining characteristics occur from the fine-grained calcarenitic limestone that comprises the majority of the formation. The base of the SCU is defined as the contact with the highly permeable, fractured dolomites of the Avon Park Formation. The entire SCU may include part of the Ocala Limestone, all of the Ocala Limestone, or the Ocala and upper portion of the Avon Park Formation.

The highly transmissive zone that occurs in the sucrosic, fractured dolomites of the Avon Park Formation is the lower permeable zone (LPZ) of the UFA. This zone, typically identified on the caliper log as fracturing and showing high resistivity values associated with dolostone or dolomitic limestone, is regionally extensive throughout the study area. The bottom boundary of the UFA is the top of interbedded dolostone and evaporites named the middle confining unit (MCU). The MCU is defined as the first occurrence of gypsiferous dolomite and anhydrite lithology.

On a regional scale, there is little evidence of a good hydraulic connection between the SA and the UFA in the area from Lake Hancock to Zolfo Springs based on the following observations (Basso, 2003):

1. There is a relatively thick sequence of low permeability sediments that separates the SA from the UFA. Thickness of the IAS (with associated confining units) ranges from about 170 ft near Bartow to 350 ft near Zolfo Springs.

2. The Upper Floridan aquifer potentiometric surface fluctuates as much as 40 feet seasonally but also shows regional long-term declines of 30 to 40 feet from Bartow to Zolfo Springs. Potentiometric surface declines in the UFA, from the headwaters to Zolfo Springs, show little attenuation due to vertical leakage from the SA.

3. The long-term average hydraulic head difference between the SA and UFA is greater than 50 feet from Lake Hancock to north-central Hardee County.

4. Leakance coefficients of the intermediate confining units range from 1×10^{-6} ft/day/ft to 9×10^{-5} ft/day/ft based on regional models by Yobbi (1996) and Metz (1995). These values indicate a tightly confined UFA.

5. Based on recharge (leakage) from the SA to the Upper UFA of 1 to 6 inches/year from the SWFWMD Eastern Tampa Bay model and a hydraulic head difference of 50 feet, calculated leakance coefficients would vary from 5×10^{-6} ft/day/ft to 1.5×10^{-5} ft/day/ft.

C. Water Use

The history of water use in the area has been studied by Stewart (1966), Kaufman (1967), Robertson (1974), Duerr and Sohm (1983), Barcelo (1990), Marella (1992), and Beach (2003). Robertson's work is the only study that provides an estimation of early water use. His estimation covered the period from 1935 to 1970. Robertson's estimates (Figure 14) were based on: metered municipal wells; measurement of discharge of many industrial and irrigation wells; a relationship between electrical power consumption and pumpage from pilot wells for extrapolation of pumpage to wells where only power consumption was known; and determining the relation between pumpage and tons of phosphate production, boxes of citrus production, and acres of citrus irrigated at pilot areas for extrapolation of pumpage to the total area of investigation. The effects of increasing water use are observable in the hydrographs of wells and lakes throughout the area (Figures 14, 15, 16 and 17). The Coley Deep well is located on the Lake Wales Ridge near Crooked Lake, while the ROMP 60 well is located to the west of the Ridge area where groundwater withdrawals for agriculture and mining were most significant. Hydrographs for the two wells show a decrease in water levels concurrent with increased water use.

Figures 16 and 17 present five year moving averages of water level fluctuations for wells and lakes with at least 25 years of record, many of which have early data pre-dating 1965. Wells and lakes with data starting in 1955 or earlier were adjusted so that all the water levels start at zero feet in 1955. Wells and lakes with data starting after 1955 were adjusted to zero using the first data point available. This approach allows a quick review of the variation of lake and well fluctuations relative to the rest. Graphs with data starting as early as 1955 show a decline in water levels which appears to occur around 1965 for the lakes and slightly earlier, around 1960 or so, in the wells. Wells such as ROMP 60 located to the west in the area of the most significant groundwater withdrawals show the earliest response to pumping. Figure 16 indicates that Crooked Lake exhibited the earliest and most severe lake level decline. The timing of the decline and the severity is consistent with the history of water use in the area.

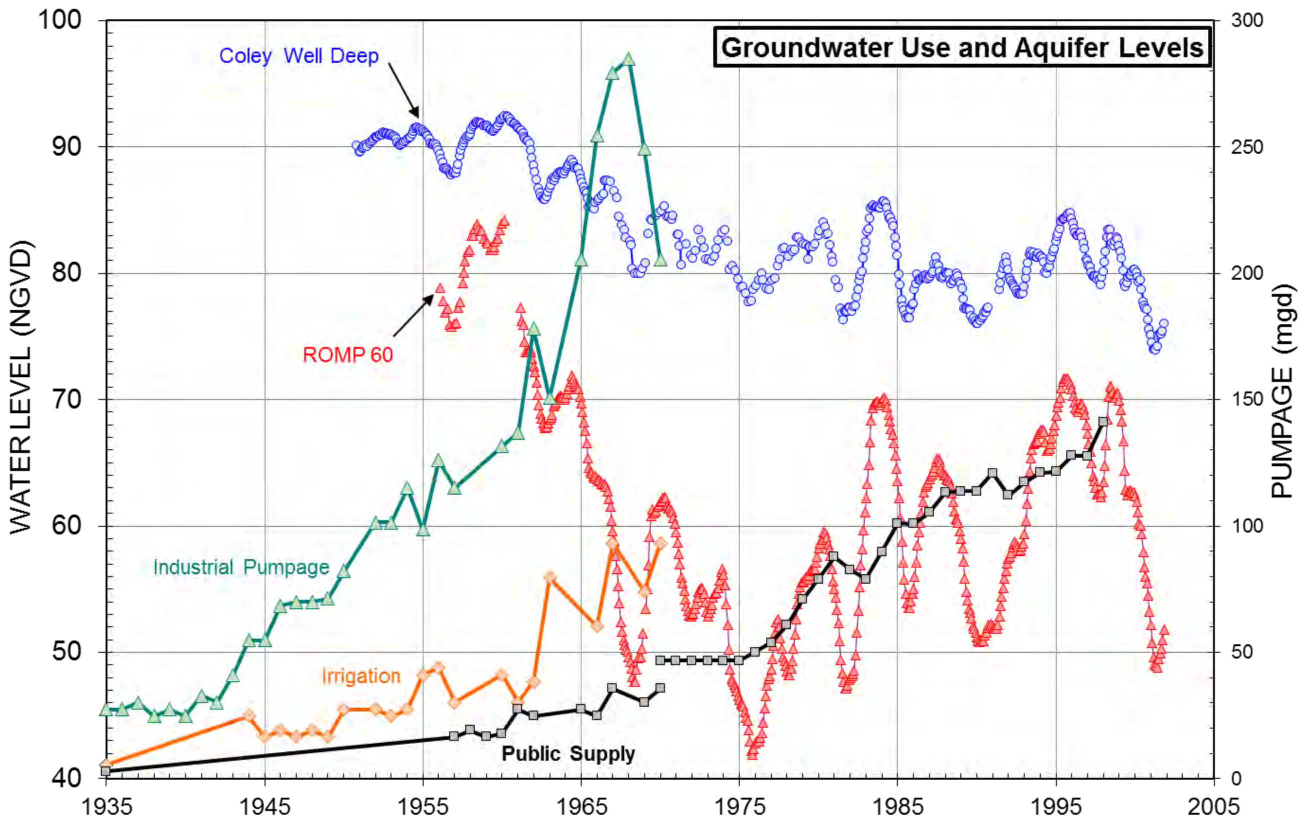

Figure 14. Early water use estimates for public supply, irrigation and industrial pumping (Robertson 1974) and hydrographs of two Upper Floridan aquifer wells (Coley Deep, ROMP 60) near Lake Hancock.

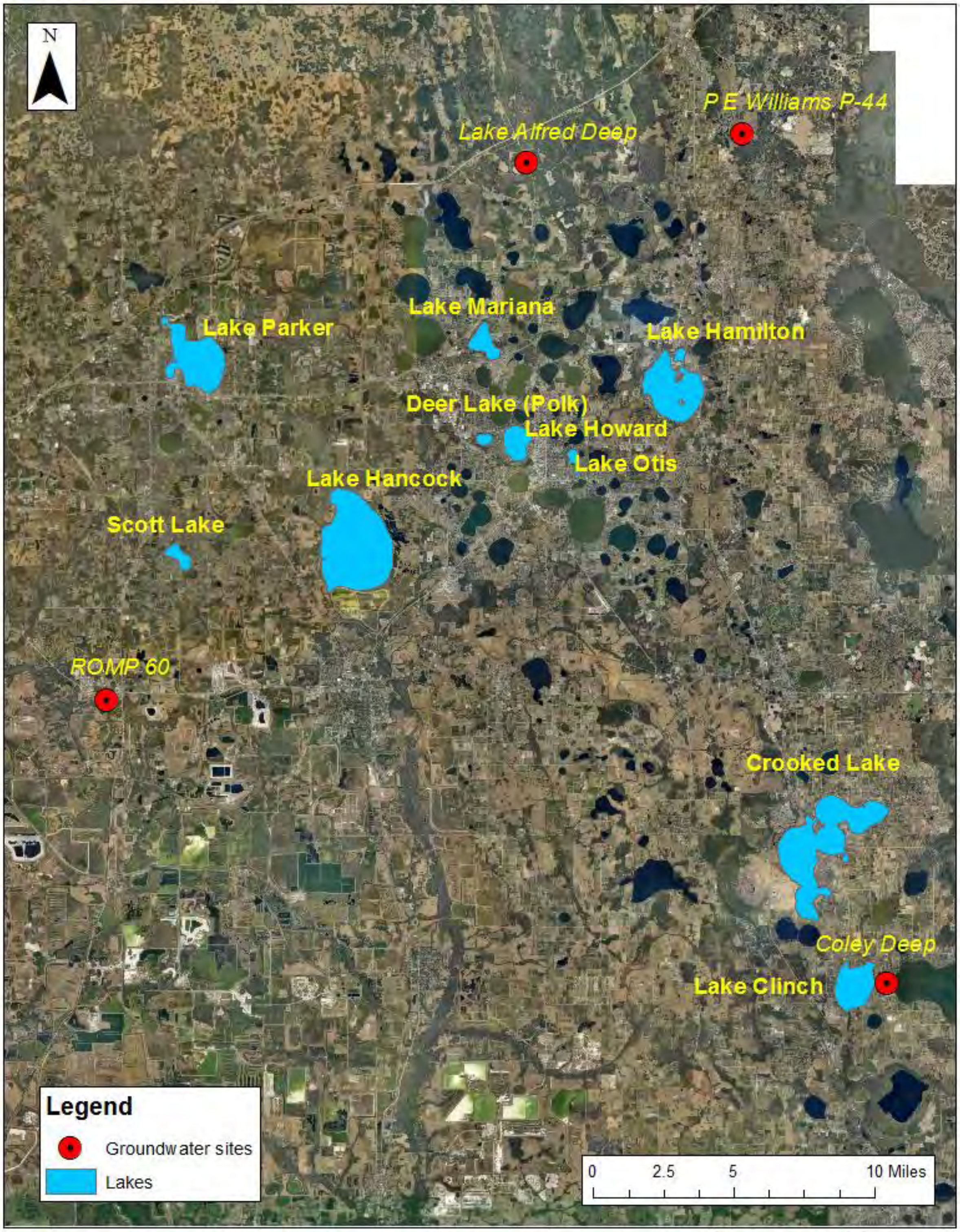

Figure 15. Location of monitoring wells and lakes represented in figures 16 and 17.

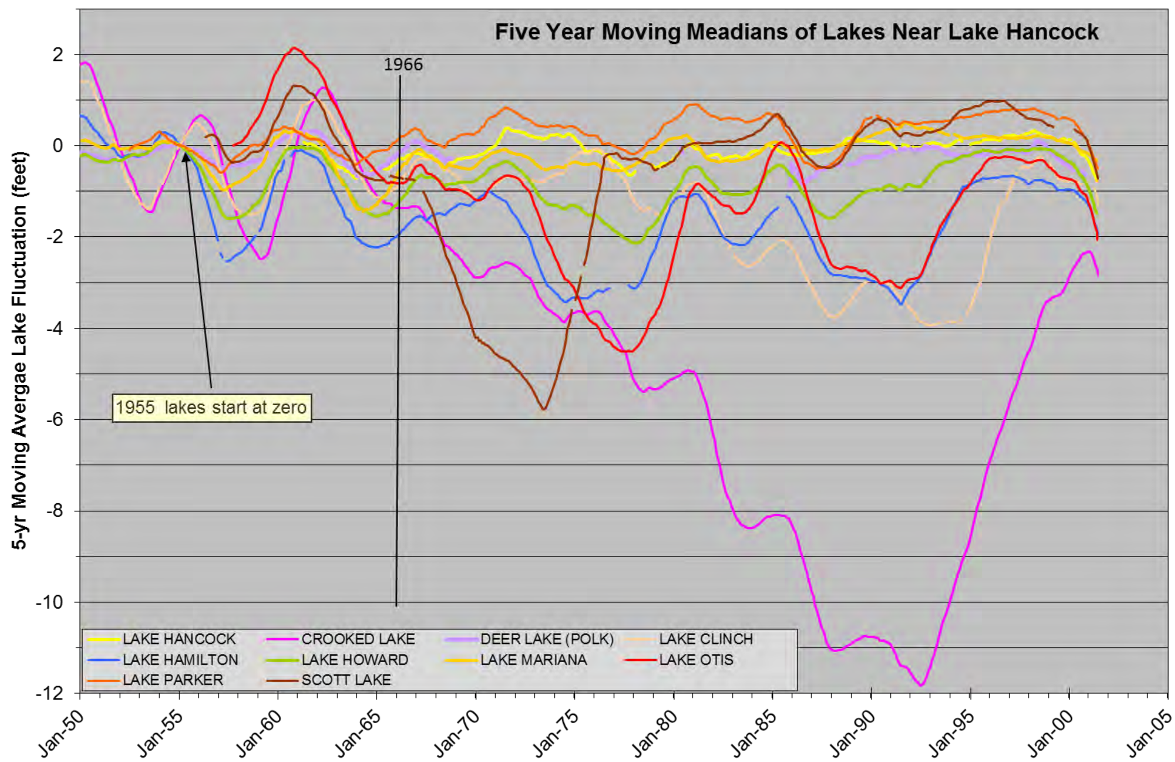

Figure 16. Five year moving averages for lakes near Lake Hancock.

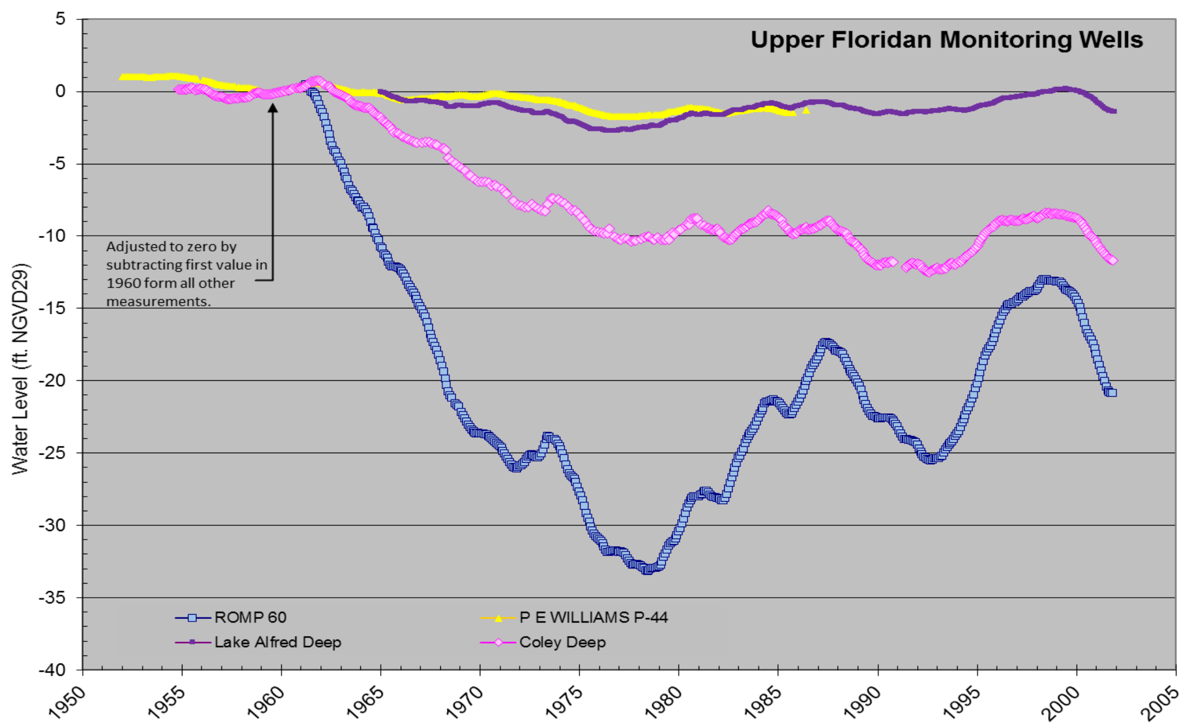

Figure 17. Five Year moving averages for Upper Floridan aquifer monitoring wells near Lake Hancock.

Detailed water use near Lake Hancock was obtained from the District's annual estimated water use report. Estimated water use reports are available starting in 1992 and are current through 2012 (SWFWMD 2013). The water use data included in these reports are primarily from the District Water Use Permitting (WUP) database in the Water Management Information System (WMIS). The water quantity data is derived from metered withdrawal points and from estimates applied to unmetered withdrawal points. Population data is based on population numbers given by public supply permittees on the Public Supply Annual Report (PSAR) forms and functional BEBR population data. About 81 percent of the water use in this report is based on directly metered withdrawals. Since the total water use contains an element of estimation, the annual report is referred to as the "Estimated Water Use Report."

Individual withdrawal point locations near Lake Hancock are shown in Figure 18 and graphs depicting total water use within specified radial distances from a central point within the lake are presented in Figures 19 and 20. Water use within the first mile of the central point is zero since this region is contained within the lake. Water use for the area within two miles of the central point is less than 1 mgd. At three miles, the water use ranges between 1 to 6 mgd with an average around 2 mgd. At five miles, water use ranges from 2 to 18 mgd with an average around 7 mgd. At six miles, the water use ranges from 6 to 26 mgd with an average around 12 mgd. From 2003 on water use has decreased slightly.

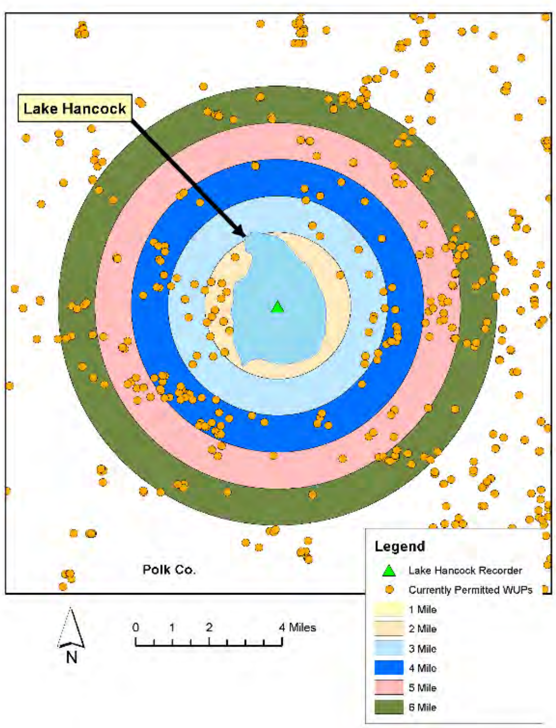

Figure 18. Location of withdrawals near Lake Hancock.

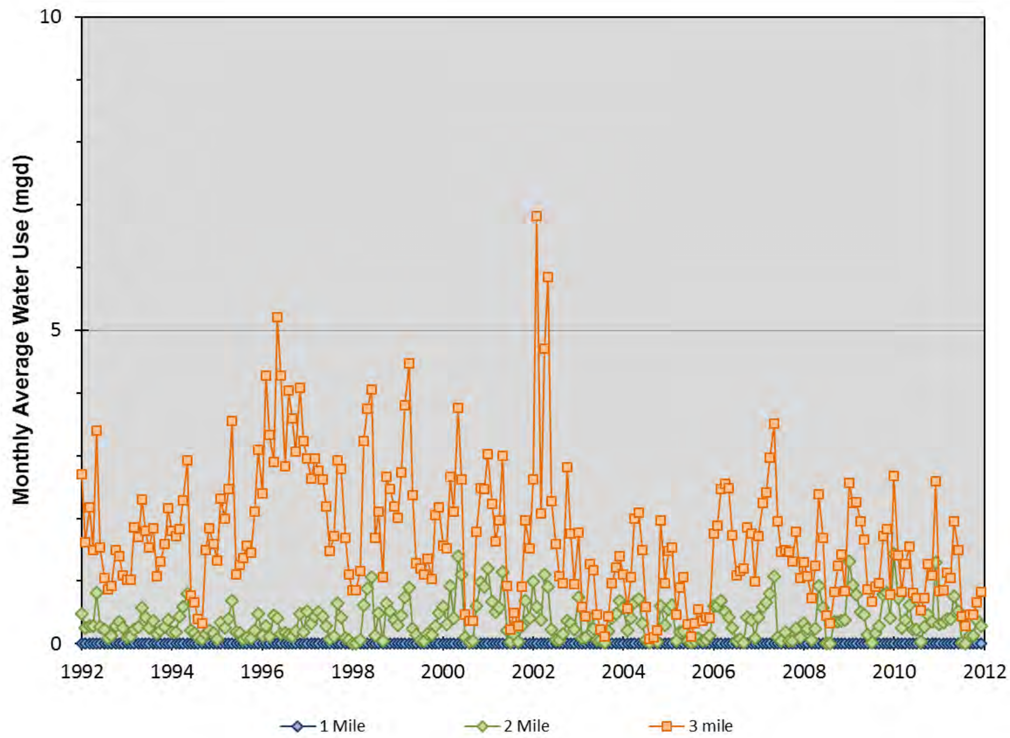

Figure 19. Metered and estimated water use within 1, 2 and 3 miles of a centroid within Lake Hancock.

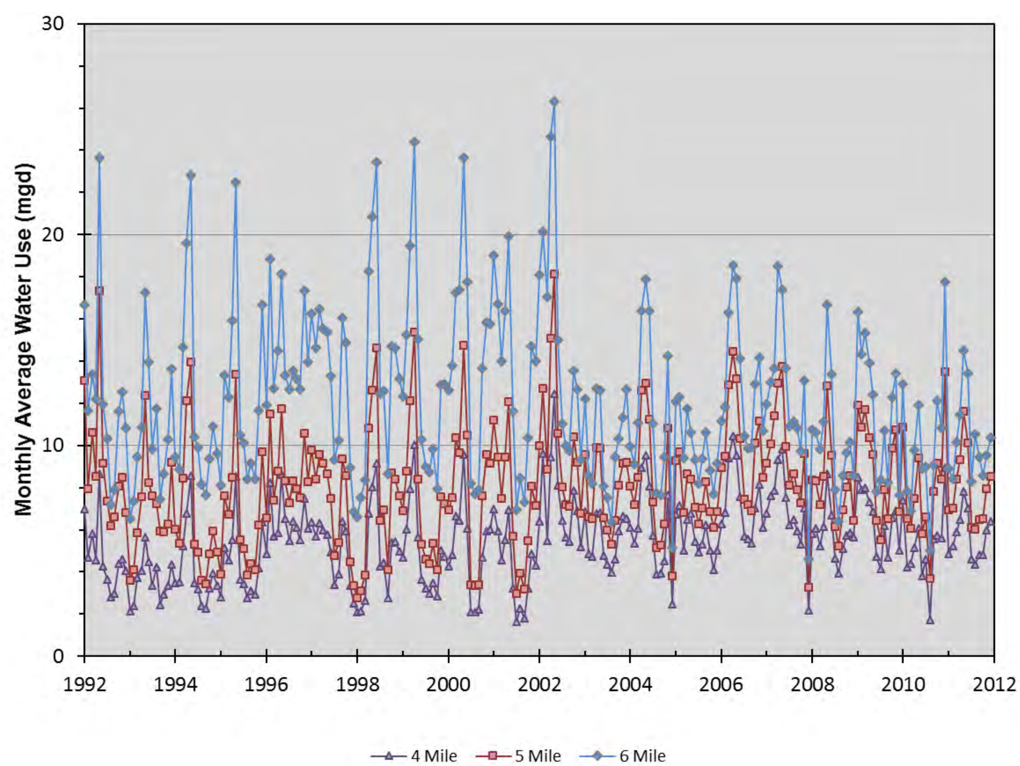

Figure 20. Metered and estimated water use within 4, 5 and 6 miles of a centroid within Lake Hancock. Note that y-axis scale differs from that shown in Figure 19.

D. Evaluation of potential Groundwater Withdrawal Impacts

Impacts of groundwater withdrawals on the Lake Hancock area were evaluated through review of historic water levels and use of groundwater models. A review of long-term water levels for Lake Hancock indicated little change in long-term lake levels. This suggests there is little evidence the lake has been significantly affected by groundwater withdrawals. It is also recognized, however, that the P11 structure on the southern end of the lake could be operated in a manner to retain water in the lake, resulting in stable lake levels but less downstream flow in the river.

Lake Hancock is in an area that has experienced substantial change in UFA groundwater levels over the years. Groundwater flow is generally from the north/northeast to the south/southwest across the lake. Based on data collected near the lake since 2009, UFA water levels average about 23 feet higher in the north/northeast portions of the lake basin than in the southwestern portion of the basin. In the northern and eastern portions of the basin, the head difference between the lake and UFA averages 2 to 6 feet and in some years is negative, indicating the potential for the lake to receive upward flow from the UFA. In the southern and western portions of the lake basin the head differences average 17 to 26 feet, indicating fairly good separation between the lake and UFA.

The groundwater models used to assess effects of withdrawals were the Peace River Integrated Model (PRIM; HydroGeoLogic, Inc., 2011 and 2012), the East-Central Florida Transient (ECFT) Model (USGS, 2012) and the District-wide Regulatory Model (DWRM). The three models were used because they include slightly different conceptualizations and it was important to determine whether they would yield similar results for assessments of Lake Hancock water levels. The PRIM is a fully integrated model and the ECFT model may be described as a quasi-integrated model. These two models are transient models that are supplied rainfall and irrigation, and calculate surface runoff and recharge to the water table, whereas in the DWRM, net recharge is determined externally and then applied directly to the water table. To estimate effects of groundwater withdrawals on the surficial and Upper Floridan aquifers, each model was run with a 50 percent reduction in groundwater withdrawals. This was done to avoid the potential problems that can occur with models when withdrawals are completely removed from the simulation, such as the occurrence of predicted water levels that are above land surface. These types of issues are especially of concern when the model is not calibrated to a “no-pumping” condition. The magnitude of water level recovery in each run was interpreted as the drawdown or change in water levels due to pumping a quantity equivalent to the 50 percent reduced pumping quantity. To estimate drawdown or change associated with all pumping, i.e., 100 percent of the current pumping quantities, values predicted for the 50 percent withdrawal reduction scenarios were doubled.

With respect to the UFA, water level changes at the center of the lake predicted for the 50 percent reduction scenarios using all three models were about 6 to 7.5 feet, for a total estimated change of 12 to 15 feet. For the SA, the ECFT and PRIM models were generally consistent and showed water level changes to be on the order of 0.5 feet or less in the eastern to northwestern portions of the lake basin (total change on the order of 0.5 to 1 feet). Areas of greatest change were in the south/southwestern portions of the basin and are generally on the order of 0.5 to 1 foot for a total potential change of over 1 foot. The DWRM indicated drawdowns on the order of 0.5 feet (total estimated change of 1.0) adjacent the lake in northern portions of the basin and upwards of 2 feet (total estimated change of 4 feet) in southern portions of the basin.

Of the three models, the PRIM model was conceptualized with greater focus on lakes, and was developed to gain a better understanding of the hydrologic processes and interactions that affect the Peace River Basin and flows in the river. The model was developed to assist in identifying the effects of previous development in the watershed and for identification and evaluation of projects designed to support minimum flow recovery goals for the Peace River. PRIM is an integrated groundwater-surface water model and was developed using the MODFLOW Hydrologic Modeling System (MODHMS®) simulation software (HydroGeoLogic, Inc., 2007). The PRIM model is comprised of a MODFLOW-like groundwater component that includes the SA, the IAS and the UFA. The groundwater (subsurface) component is linked to a surface water component that simulates watershed processes, including rainfall and evapotranspiration (ET), streamflow, overland flow, lakes, and hydraulic structures. The hydrologic processes among all components are coupled through water flux terms, such as infiltration, recharge, soil and groundwater ET, lake and stream leakage, groundwater discharge to streams, redistribution of water from groundwater withdrawals, irrigation infiltration, and return flows. The PRIM is driven by daily rainfall stress periods, monthly ET, and withdrawal and discharge (i.e., groundwater pumping and National Pollutant Discharge Elimination System [NPDES] discharges) stress periods. The model was calibrated to a nine-year period from 1994 through 2002. The calibrated model was extended to cover a thirteen-year period from 1994 through 2006.

The Groundwater Withdrawal scenario run with PRIM addressed the impact of changes in groundwater pumping. Specifically, the effects of reducing pumping in the Base Case scenario to 50% was evaluated. Because in the PRIM all water withdrawn from either groundwater or surface water in the basin is returned as either a point (NPDES) discharge or distributed across the land surface, reductions in groundwater withdrawals caused a proportional reduction in these return flows. As expected, reductions in groundwater extraction generally lead to higher lake levels. On the whole, however, the model indicates that changes in groundwater pumping has little effect on Lake Hancock. The sensitivity of lake levels to groundwater heads (and therefore to groundwater withdrawals) is greatest at the 90th exceedance percentile level (i.e., under low lake levels conditions). These correspond to dry periods when lakes receive little surface water inflow to maintain lake levels. At the 50th percentile of lake levels and above, results indicate little or no sensitivity to groundwater withdrawals at Lake Hancock. The 50% reduction in groundwater withdrawals resulted in less than 0.1 ft. change in the P10 (i.e., at a relatively high lake level) and P50 and a 0.1 ft. increase in the P90. The results of the PRIM model indicate that Lake Hancock is not sensitive to groundwater withdrawals.

E. Rainfall Regression Long-Term Historic Lake Percentile Estimation

The procedure to establish minimum and guidance levels for lakes is based on long-term lake stage percentiles. In the absence of a long-term water level data, a rainfall based regression model may be constructed and used to model lake stage fluctuations and create a long-term water level record. A first step in developing a rainfall regression model is the delineation of “Historic” and “Current” time periods. A Historic time period is a period when there are little to no groundwater withdrawal impacts on the lake, and the lake’s structural condition is similar or the same as the present day. In contrast, a Current time period is a recent long-term period during which withdrawals and structural alterations are stable. To identify Historic and Current time periods, an evaluation of hydrologic changes in the vicinity of the lake is completed to determine if the water body has been significantly impacted by groundwater withdrawals. Examples of hydrological changes that are reviewed include drainage modifications, dredging, filling and modifications to the lake outlets.

Data from the Historic period are typically used to establish a statistical relationship (regression) with rainfall. This rainfall regression is then used to extend the available stage record (i.e., develop a 60 year or longer record) for calculation of long-term P10, P50 (median), and P90 lake stage percentiles. The P10, P50 and P90 are, respectively, the water level elevations equaled or exceeded ten, fifty and ninety percent of the time on a long-term basis. The rainfall regression model can then be used to evaluate whether the lake is fluctuating consistently with rainfall and can also be used for assessing whether minimum levels are being met.

The rainfall regression method (Ellison, 2014) involves development of a Line of Organic Correlation (LOC) between lake stage and rainfall. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 1992). The magnitude of the slope of the LOC line is calculated as the ratio of the standard deviations of the x and y variables and its sign, i.e., whether it is positive or negative, determined by the sign (+ or -) of the correlation coefficient (r). The LOC approach, rather than a simple linear regression approach is preferable for the rainfall-regression method since it produces a result that better retains the variance (and therefore retains the "character") of the original data.

Rainfall for the LOC model is correlated with lake water level data using inverse linearly-weighted rainfall sums. The weighted-sums ascribe higher weight to more recent rainfall and progressively less weight to rainfall in the past. For the rainfall regression method, weighted sums varying from 6 months to 10 years are used to develop separate models, and the model with the highest coefficient of determination (r^2) is chosen as the best-fit model.

Lake Hancock Water Level Data and Identification of Historic Data

Stage data has been measured ate two gage sites within Lake Hancock (Figure 21). The first, site identification number (SID 24760), was monitored by the U.S. Geological USGS since October 23, 1958. The second gage (SID 24532) was installed on October 7, 2002 and is a District maintained gage.

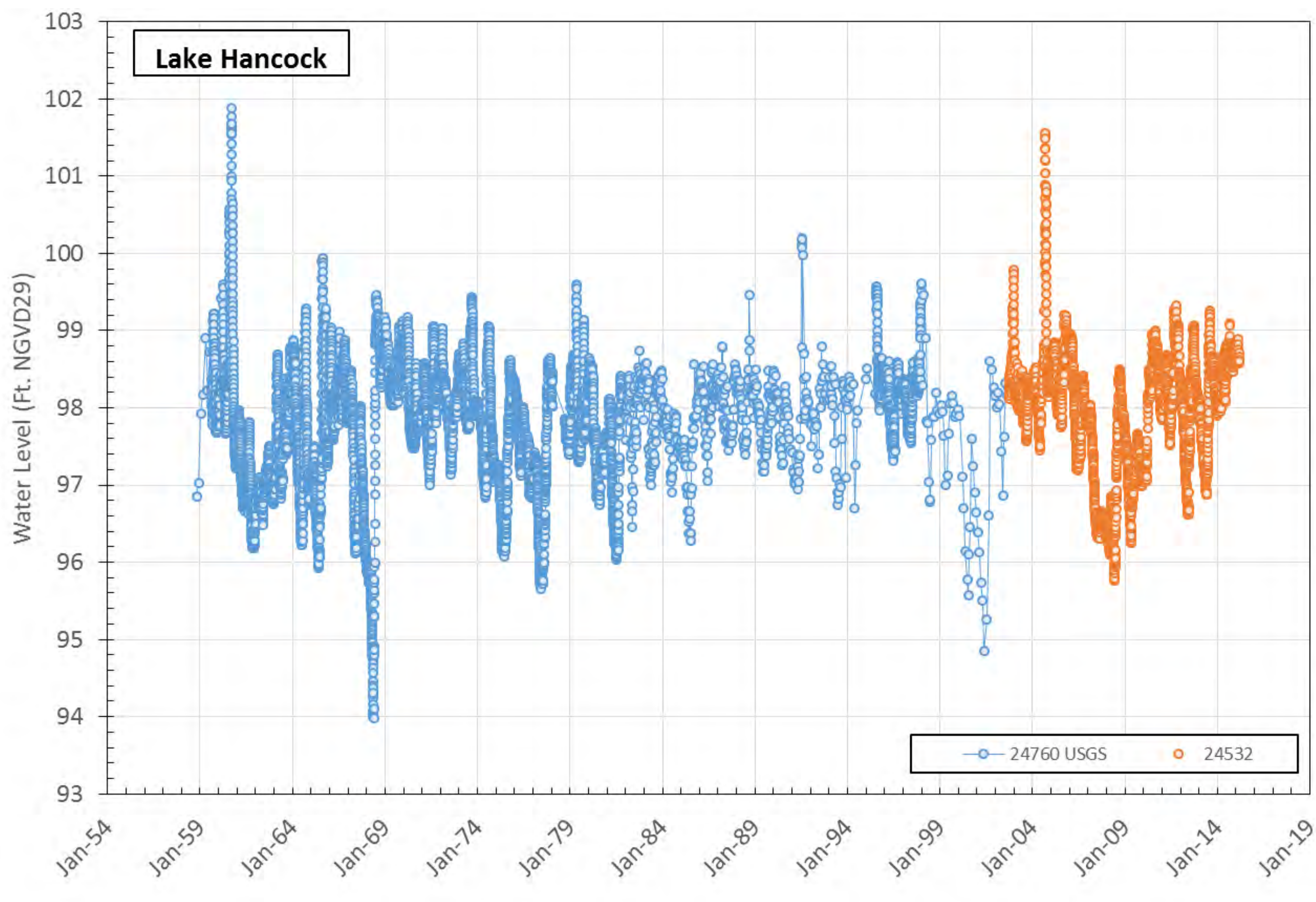

Figure 21. Lake Hancock Hydrograph.

Review of water use data and hydrographs for wells and lakes in the area near Lake Hancock indicates a period prior to 1965 can be used as near-historic conditions. As discussed in Section C of this memorandum, water levels in wells near the lake began to exhibit impacts from pumping around 1960 while the lakes started to show impacts around 1965. Based on the water use history and hydrographs for area wells, the historic period was established as data pre-dating 1965. Structural changes to the Lake Hancock outlet occurred in 1963, and more recently in 2010; but operation of the outlet structures appears to have been rather consistent through time based on lake water levels. For example, intense rain events such as occurred in 1960 and 2004 produced very similar extreme highs (Figure 21).

Rain Gauge Selection

Available rain gage data were inventoried and sorted by distance from Lake Hancock and their period of record (POR) (Tables 1 and 2) to determine the nearest gauges located in drainage basins connected to Lake Hancock with adequate record to construct a LOC Model. There was only one gauge, National Weather Service's Lakeland (Linder Regional Airport, SID 18843), located in a basin connected to and up-gradient of Lake Hancock with records extending far enough back in time to support the calibration of the LOC model. This gauge also served as the primary rain data used in the model up to December 2001. This gauge is located in the Saddle Creek basin (Figure 22). The period of record for this gauge is April 30, 1915 to December 31, 2001. Missing days of data at this gauge were infilled with estimated values (Aly, 2008). After Linder Regional Airport gauge was shut down on December 31, 2001 the Lakeland 2 National Weather Service (NWS) gauge (SID 18048) was used. Missing days of data at the Lakeland 2 gauge were infilled with data from the Lakeland Public Works. The remaining gauges listed in tables 1 and 2 either had short data periods or are located down gradient of the lake.

Table 1. Rain gauges sorted by distance from Lake Hancock.

Site ID	Site Name	POR Begin	POR End	No. of Samples	Largest Gap (Days)	Status	Distance Miles
25150	LAKE HANCOCK	5/15/1993	10/21/2014	316,732	328	Cancelled	2.2
838153	SADDLE CREEK AT P-11 ET	3/26/2014	8/12/2014	13,371	0	Active	2.2
25165	PEACE AT BARTOW	10/31/1987	6/23/2000	68,401	1	Inactive	4.6
25164	BARTOW NWS	1/1/1901	1/28/2015	64,350	31	Cancelled	4.7
705757	BARTOW SERVICE OFFICE	2/9/2008	6/19/2012	152,840	0	Cancelled	5.2
18121	LAKELAND SOUTH	5/31/1997	7/31/2000	1,158	1	Inactive	5.8
24752	LAKE SHIPP	12/31/1984	9/30/1989	1,735	1	Inactive	6.0
24534	WINTER HAVEN NWS	12/31/1940	2/29/2008	24,534	2	Cancelled	6.2
24845	LAKE HOWARD	3/31/1987	9/15/1991	1,630	1	Inactive	6.7
24499	EBERSBACH	12/31/1975	7/31/1987	4,231	1	Inactive	7.0
24497	CLEAR SPRINGS	12/31/1991	4/30/1997	1,948	1	Inactive	7.1
25176	LAKELAND PUBLIC WORKS	8/31/1989	3/3/2015	396,224	1	Active	7.3
25167	ROMP 73 WINTER HAVEN	6/23/1998	3/23/2015	384,738	1	Active	7.3
25175	AUBURNDALE	6/30/2000	6/30/2005	1,827	1	Inactive	7.8
17954	LAKELAND TOWER	12/31/1970	4/30/1998	9,983	1	Inactive	8.1
844099	WINTER HAVEN GILBERT AIRPORT NWS	4/1/1998	1/27/2015	6,061	10	Active	8.2
18843	LAKELAND (LINDER REGIONAL AIRPORT) NWS	4/30/1915	12/31/2001	31,658	1	Cancelled	9.0
24494	CYPRESS GARDENS	12/31/1970	1/31/1998	9,894	1	Inactive	9.1

Table 2. Rain gauges sorted by period of record.

Site ID	Site Name	POR Begin	POR End	No. of Samples	Largest Gap (Days)	Status	Distance Miles
25164	BARTOW NWS	1/1/1901	1/28/2015	64,350	31	Cancelled	4.7
18843	LAKELAND (LINDER REGIONAL AIRPORT) NWS	4/30/1915	12/31/2001	31,658	1	Cancelled	9.0
24534	WINTER HAVEN NWS	12/31/1940	2/29/2008	24,534	2	Cancelled	6.2
24494	CYPRESS GARDENS	12/31/1970	1/31/1998	9,894	1	Inactive	9.1
17954	LAKELAND TOWER	12/31/1970	4/30/1998	9,983	1	Inactive	8.1
24499	EBERSBACH	12/31/1975	7/31/1987	4,231	1	Inactive	7.0
24752	LAKE SHIPP	12/31/1984	9/30/1989	1,735	1	Inactive	6.0
24845	LAKE HOWARD	3/31/1987	9/15/1991	1,630	1	Inactive	6.7
25165	PEACE AT BARTOW	10/31/1987	6/23/2000	68,401	1	Inactive	4.6
25176	LAKELAND PUBLIC WORKS	8/31/1989	3/3/2015	396,224	1	Active	7.3
24497	CLEAR SPRINGS	12/31/1991	4/30/1997	1,948	1	Inactive	7.1
25150	LAKE HANCOCK	5/15/1993	10/21/2014	316,732	328	Cancelled	2.2
18121	LAKELAND SOUTH	5/31/1997	7/31/2000	1,158	1	Inactive	5.8
844099	WINTER HAVEN GILBERT AIRPORT NWS	4/1/1998	1/27/2015	6,061	10	Active	8.2
25167	ROMP 73 WINTER HAVEN	6/23/1998	3/23/2015	384,738	1	Active	7.3
25175	AUBURNDALE	6/30/2000	6/30/2005	1,827	1	Inactive	7.8
705757	BARTOW SERVICE OFFICE	2/9/2008	6/19/2012	152,840	0	Cancelled	5.2
838153	SADDLE CREEK AT P-11 ET	3/26/2014	8/12/2014	13,371	0	Active	2.2

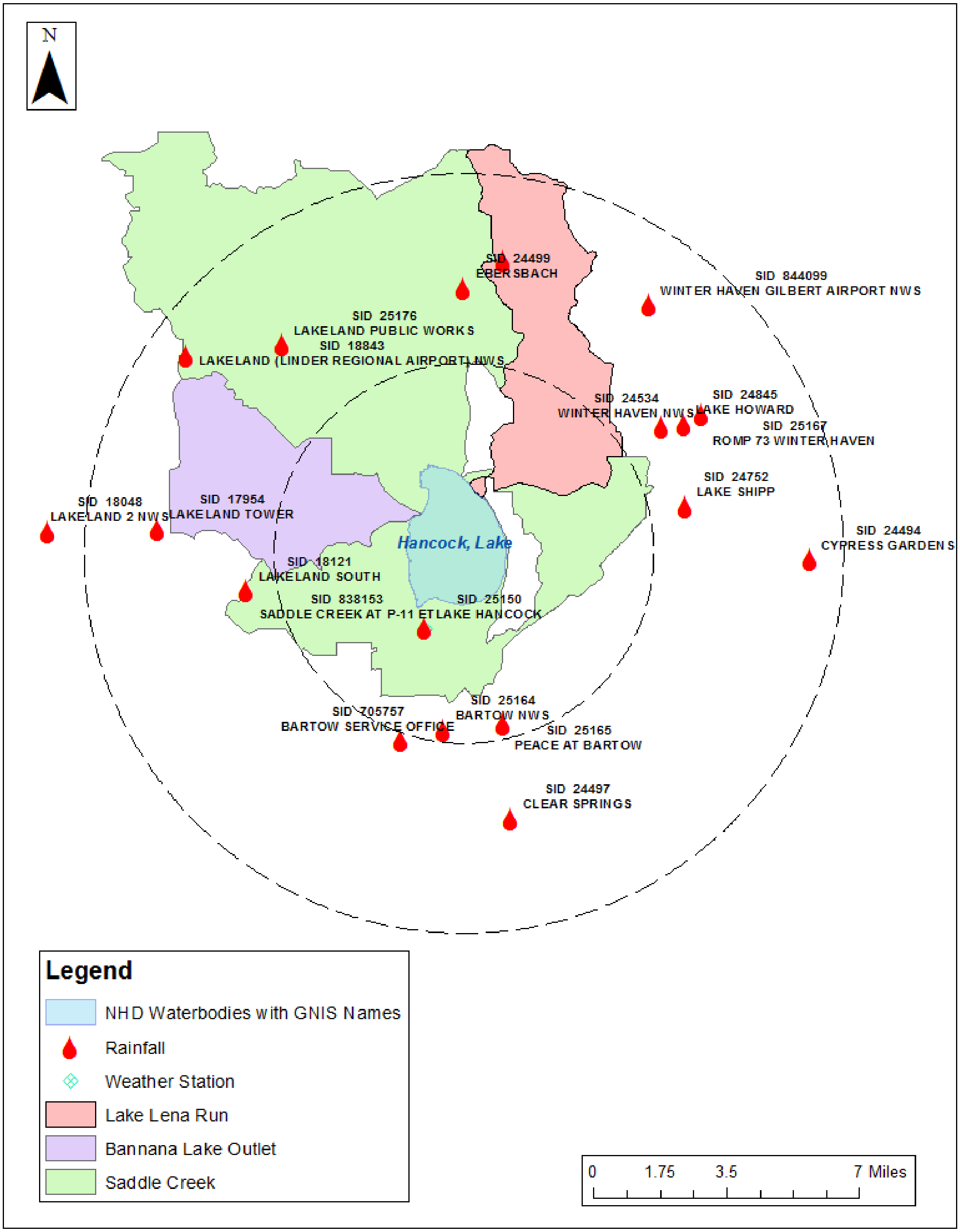

Figure 22. Location of rain gauges listed in Tables 1 and 2.

Lake Hancock Rainfall Regression Model and Historic Percentiles

Rainfall regression LOC models were developed using lake stage data and rainfall data from December 1958 through 1965. Data collected after this period were conservatively excluded from model development to preclude inclusion of records that could reflect potential effects from groundwater withdrawals. The best-fit LOC model for predicting water levels in Lake Hancock (Figure 23) exhibited a coefficient of determination (r^2) of 0.53 and may be simplified as:

$$\hat{y}_i = b_0 + sign[r] * b_i * x_i \qquad \text{(Equation 1)}$$

where

$\hat{y}_i =$ *the estimate of lake stage expressed as an elevation in feet above NGVD29*

$b_0 =$ *the y intercept, in this case 94.50 feet above NGVD29*

$b_i =$ *the regression slope; in this case 0.1236731*

$sign[r] =$ *the algebraic sign (+ or -) of the correlation coefficient; in this case "+"*

$x_i =$ the *inversely, linearly-weighted one-year cumulative rainfall sum in inches*

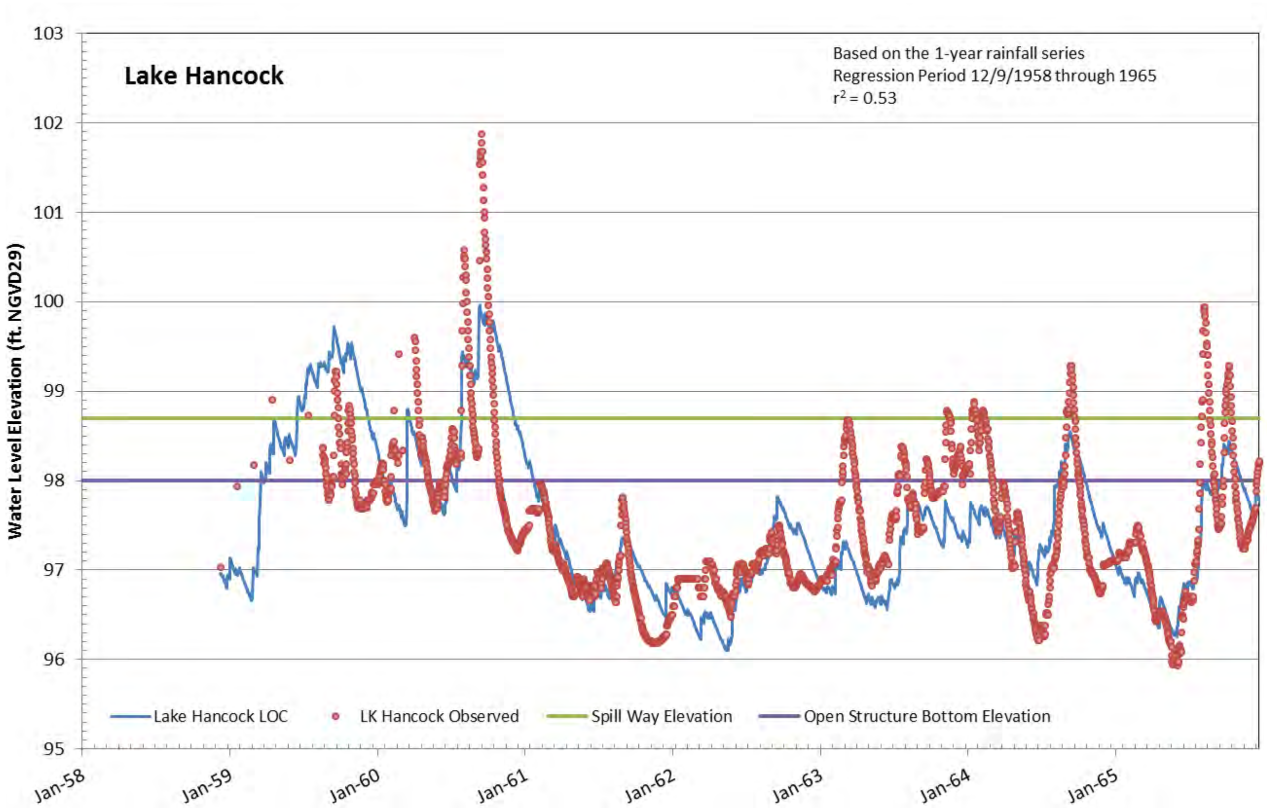

Figure 23. Calibration period rainfall regression model results (solid blue line) plotted with observed lake level data (red circles).

The calibration period model residuals plot in fairly even pattern around the regression model line and the upper and lower 95th prediction intervals lie slightly greater than one foot from the regression model line (Figure 24). A comparison of measured and modeled percentiles for the calibration period is presented in Table 3. The model-derived P10 for the calibration period was 0.3 feet higher than the corresponding percentiles for the observed data and the model derivedP50 and P90 percentiles were equivalent to the observed values, respectively differing by less than 0.1 feet.

The best-fit LOC model was used to estimate water levels for Lake Hancock for the 68-year period from January 1, 1946 through December 2014. Model-predicted water levels match actual, i.e., observed period of record data reasonably well, indicating that the lake water levels fluctuate mostly in response to rainfall and impacts from groundwater withdrawals are minimal for most of the record (Figure 25).

Because the model produced a close match with the observed data throughout the period of record, Long-term, historic percentiles (Table 4) were developed as a composite of observed data and modeled data that was used to infill data gaps.

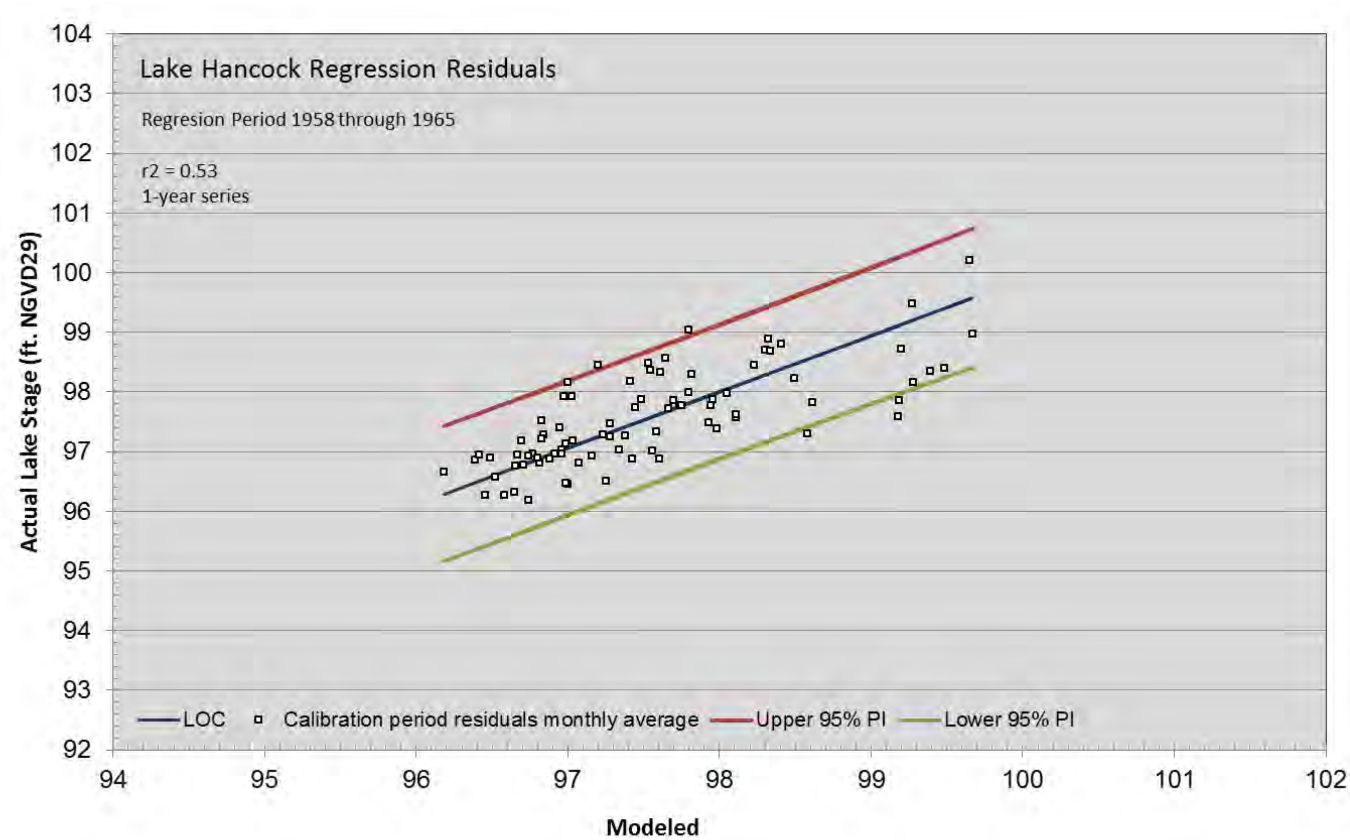

Figure 24. Rainfall regression model residuals.

Table 3. Comparison of Lake Hancock calibration period percentiles.

Calibration 1958 through 1965			
Percentiles*	**Observed** (NGVD29)	**Model** (NGVD29)	**Model Minus Observed** (feet)
P10	98.58	98.87	+0.29
P50	97.34	97.35	+0.01
P90	96.64	96.61	-0.03

* Percentiles listed include the water surface elevation equaled or exceeded ten (P10), fifty (P50) and ninety (P90) percent of the time

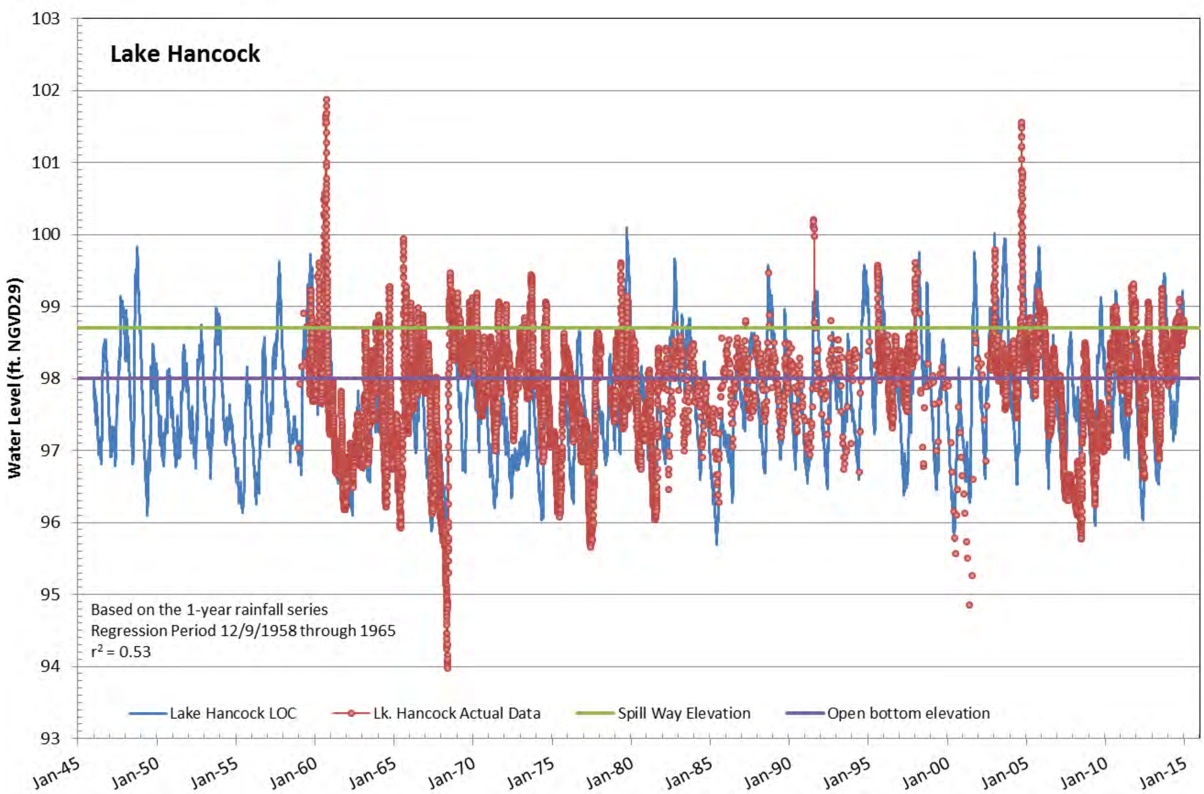

Figure 25. Rainfall regression model extension back to 1946 and forward through 2014. Model calibration period was 1958 through 1965.

Table 4. Lake Hancock Long-term Historic percentiles.

Lake Hancock Long-term, Historic Percentiles* (1946 through 2014)	
Percentiles	
P10	98.8
P50	97.6
P90	96.7

* Percentiles listed include the water surface elevation equaled or exceeded ten (P10), fifty (P50) and ninety (P90) percent of the time

F. Comparison of Lake Hancock Normal Pool Elevation and Historic Percentiles

A Normal Pool elevation is a datum established to standardize measured water levels, facilitate comparisons among wetlands and lakes, aid in the design of wetland storm water treatment systems (SWFWMD, 1988) and the development of minimum lake and wetland levels (SWFWMD 1999a, 1999b). The Normal Pool can be consistently identified in cypress swamps or cypress-ringed lakes based on similar vertical locations of several indicators of inundation (Hull, et al, 1989; Biological Research Associates, 1996, Carr et al., 2006).

Normal pool typically equals the long-term tenth percentile on non-structurally modified lake without impacts from withdrawals. A Normal Pool of 99.6 feet NGVD was determined for Lake Hancock based on median value from 31 buttress inflection points of cypress trees along the lake shore and within wetlands contiguous with the lake. The minimum buttress elevation was 98.9 feet NGVD29 which is 0.1 feet higher than the model derived historic P10. A comparison of the long-term, historic P10 of 98.8 feet for the lake with the Normal Pool elevation indicates that Lake Hancock is 0.8 feet lower than the elevation that would be expected for establishment of the existing lake-fringing forested wetlands. The similarity between the historical spillway elevation at the lake outlet (98.7 feet NGVD) and the long-term Historic P10, indicate the strong effect of structural alterations on water levels in the lake.

G. Assessment of Minimum Level Status

The goal of a minimum levels status assessment is to determine if lake levels are fluctuating in accordance with criteria associated with adopted or proposed levels, i.e., to determine whether the minimum levels are being met. In addition to use of a rainfall regression model and/or other types of models, the process includes comparison of long-term water levels with adopted or proposed levels, review of periodic groundwater modeling updates, and, if necessary, investigation of other factors that could help explain lake level fluctuations.

Since the rainfall regression model was calibrated to an historic period, it provides a method to predict lake levels absent the effects of water withdrawals. Comparison of the model results to observed data allows for assessment of impacts from groundwater withdrawals. From January 2000 through 2014 water levels predicted with the rainfall regression model and the actual observed data are in fairly close agreement (Figure 26). There are two extended periods, one in 2006 and one in 2008 where observed levels are lower than the predicted. Factors accounting for these differences are not known, but could be associated with model or data deficiencies or related to structure operation. Other than during the periods in 20016 and 2008, the model predicts observed water levels fairly well, especially considering the structure at the lake outlet is operated to manage lake levels and flow to the Peace River.

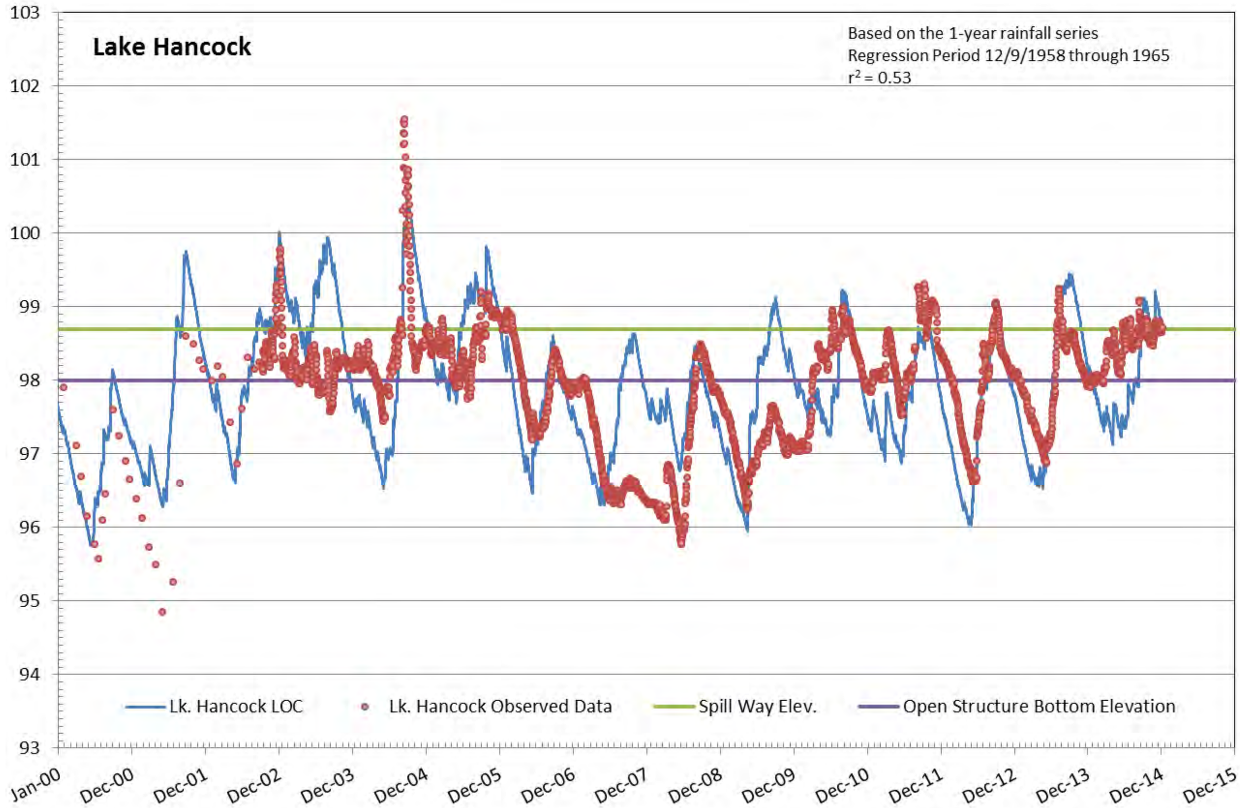

Figure 26. Model and actual data hydrograph for the period 2000 through 2014.

The use of the prediction intervals generated from the calibration period residuals (see Figure 24) provides another for evaluating the Minimum Lake Level (MLL). This approach involves modification of the LOC model line and associated prediction interval lines based on the differences in elevations associated with the Historic P50 and the MLL. For this process, the intercept for the LOC model and prediction intervals are decreased in elevation based on the difference between the Historic P50 and the MLL (Figure 27). These modified, shifted lines represent a defined range of lake levels that would be expected to meet the MLL while exhibiting variation expected due to changes in rainfall.

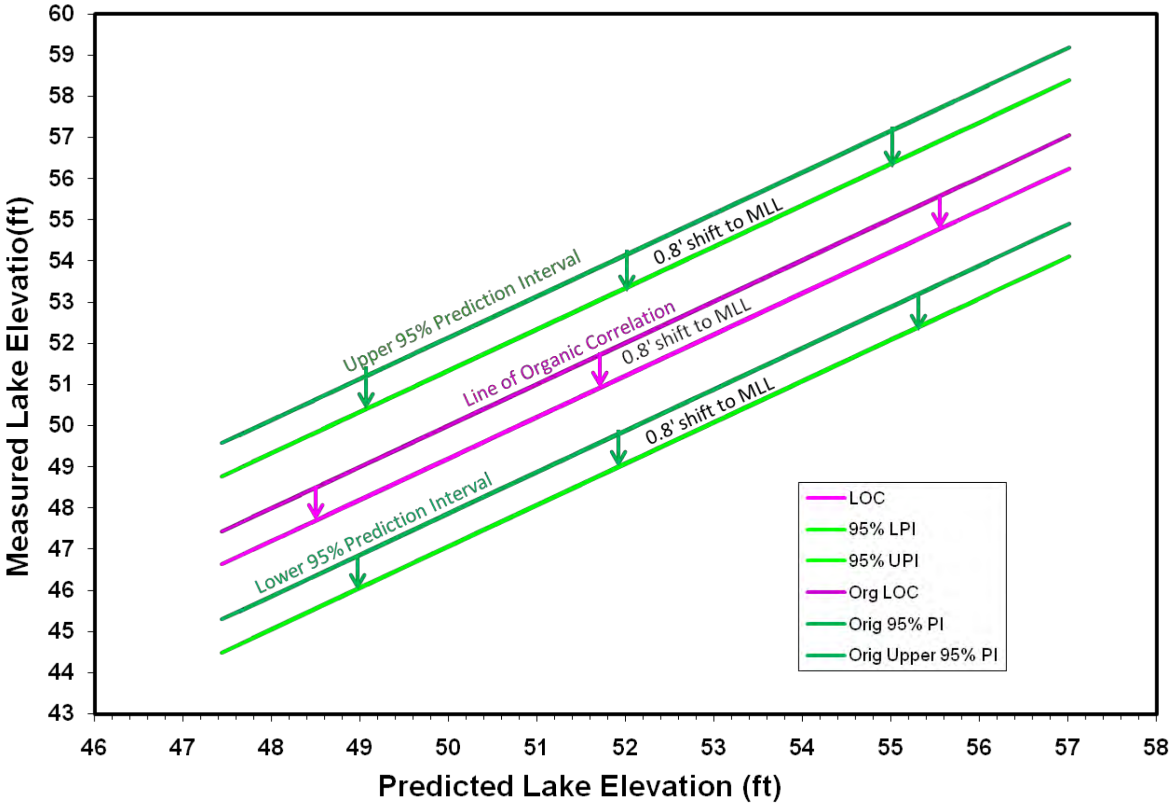

Figure 27. Example of the shifts to the prediction interval and LOC lines to reflect the MLL.

Prediction intervals for an LOC model are calculated for alpha equal to 0.025 (single tail) using the following equation (Helsel and Hirsch, 1992):

$$\left(\hat{y} - ts\sqrt{1 - \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{SS_x}}\ ,\ \hat{y} + ts\sqrt{1 - \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{SS_x}}\right); \qquad \text{(Equation 2)}$$

where

$\hat{y_i} = b_0 + sign[r] * b_i * x_i$ *the estimate of y given* x_i (refer to Equation 1)

$t = \frac{\bar{y} - \mu_0}{s/\sqrt{n}}$ *students t distribution*

$s = \sqrt{s^2}$ *standard error of the regression*

$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$ *mean x*

$SS_x = \sum_{i=1}^{n} (x_i - \bar{x}_i) = \sum_{i=1}^{n} x_i^2 - n(\bar{x})^2$ *sums of squares*

Annual updates to the rainfall regression model (LOC model) and the prediction intervals from the calibration period can be used to determine if the residuals from the updated model are within the shifted calibration period prediction intervals representing the new MLL condition. For a 95% prediction interval, it is expected that 2.5% of the points will plot below the lower prediction interval and 2.5% should plot above the upper prediction interval. However, such a strict interpretation may not be appropriate for MLL status assessments due to the variability in rainfall and the complexities in representing areal rainfall totals with point measurement taken at a gage site. Because of these and other factors such as limitations imposed on calibration to short time periods that may not include the entire range of water levels (extreme highs and record lows), the expected number of predicted water level values that may plot below the 95% prediction interval is doubled, to 5%. The occurrence of more than 5% of the predicted water level values below the lower prediction interval would suggest the lake is lower than can be accounted for based solely on rainfall, and may be affected by changes resulting from groundwater withdrawals or other factors.

The adopted MLL for Lake Hancock (97.6 feet above NGVD29) is set at the modeled Historic P50. For assessment of the MLL status, the intercept of the LOC and prediction intervals were, therefore, not shifted. Prediction interval based on annual average model and observed results were calculated (Figure 28). All plotted annual average residuals for Lake Hancock since January 2008 are above the lower prediction interval (Figure 28), indicating the MLL is being met.

Use of observed lake data provides an empirical method for assessing whether the MLL and High Minimum Lake Level (HMLL) are being met. The MLL and HMLL represent long-term exceedance percentiles for the P50 and P10, respectively; so, full assessment of the MLL and HMLL with actual percentiles requires data from a long period of record.

Assessment of the adopted MLL and HMLL for Lake Hancock using the record starting in 1959 allows for evaluation of the lake relative to the history of withdrawals in the area, which have been variable through time. Cumulative median (P50) and cumulative P10 water surface elevations were also calculated for a time period starting in 2002 and compared with the proposed MLL and HMLL. Cumulative medians for all of the evaluated start dates ended with values above the MLL (Figure 29). The cumulative P10s for the evaluated periods ended up approximately 0.1 ft. below the HMLL due to historical structure operation to maintain a maximum desirable elevation of 98.7 (Figure 29). With the exception of the structure operation to the maximum desirable elevation, the MLL and HMLL could be met based on both a long term and short term recent basis.

Because Lake Hancock is currently meeting its adopted minimum levels and the structure was recently raised to store additional water for release to the Peace River to recover minimum flows, the HMLL and the MLL are also expected to be met for the next 20-year planning period.

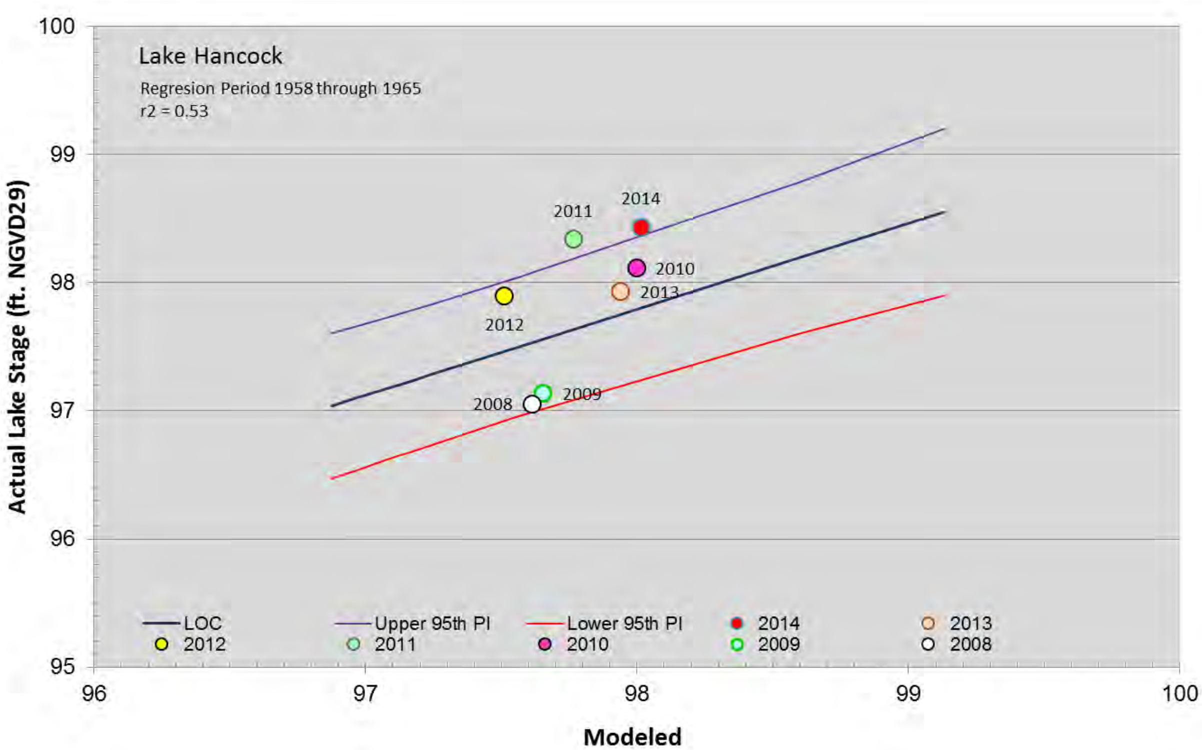

Figure 28. Model and actual data hydrograph for the period 2000 through 2014.

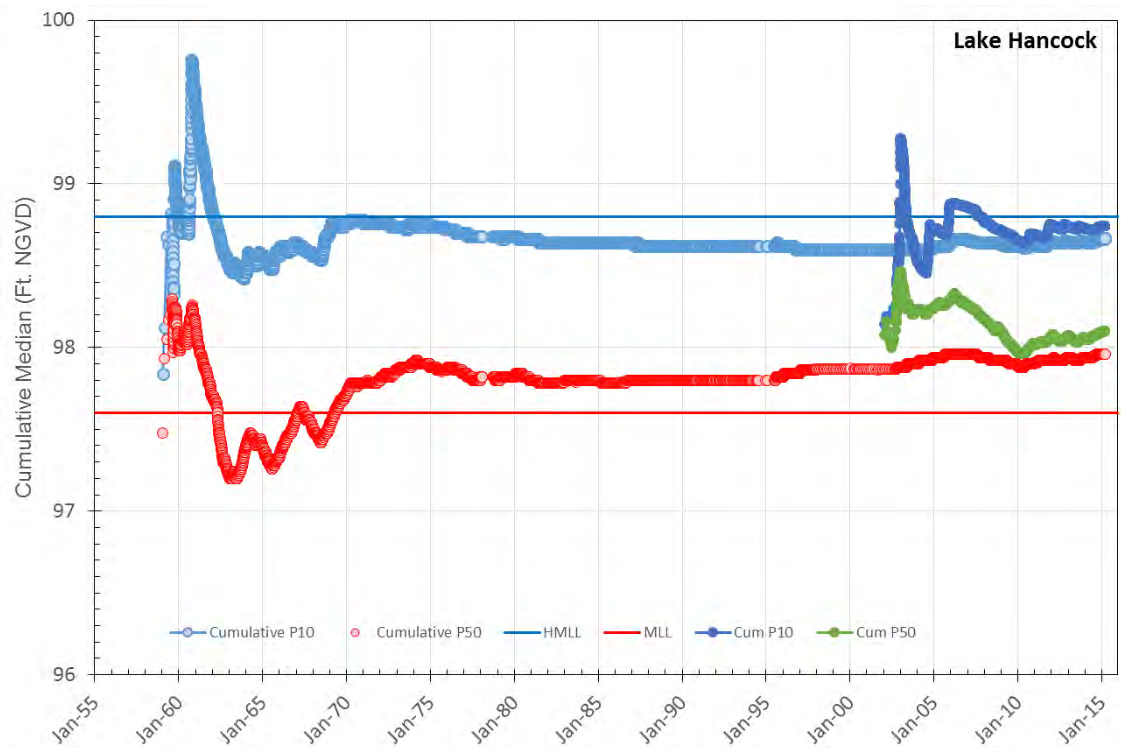

Figure 29. Cumulative median and P10 starting in 1959 and 2002.

H. Conclusions

Lake Hancock is a structurally operated lake located in a basin that has undergone extensive phosphate mining, and these factors complicate analysis of impacts associated with groundwater pumping. Fortunately, a short period of Historic lake stage data pre-dating groundwater withdrawals was available for construction of a rainfall regression model that could be used to predict long-term water levels for Lake Hancock.

Long-term water levels for Lake Hancock were simulated using a rainfall regression model. A best-fit LOC rainfall regression model was calibrated to water level data from 1959 through 1965 using weighted 1-year cumulative rainfall sums in inches. Model-predicted water levels closely matched observed water levels, indicating that Lake Hancock water level fluctuations are consistent with expectations based on variation in rainfall.

The MLL was established at the long-term Historic P50 of 97.6 feet NGVD. The HMLL was established at the long-term Historic P10 of 98.8 feet NGVD. Both minimum levels were developed using model-predicted and observed calibration period water levels.

Assessment of observed Lake Hancock water levels relative to the MLL indicates the P50 of recent lake water levels is approximately 0.3 ft. higher than the MLL. Assessment of the observed water levels relative to the HMLL indicates the lake is approximately 0.1 ft. lower than the adopted level, primarily as a result of historical structure operation to maintain a maximum desirable level of 98.7 feet NGVD29.

Because Lake Hancock is considered to currently be meeting its adopted minimum levels and the structure was recently raised to store additional water for augmentation of flows in the Peace River, the HMLL and the MLL are also expected to be met for the next 20-year planning period.

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